Volume 31 NOVEMBER, 1947 Number 11

# BULLETIN
## *of the*
# American Association *of* Petroleum Geologists

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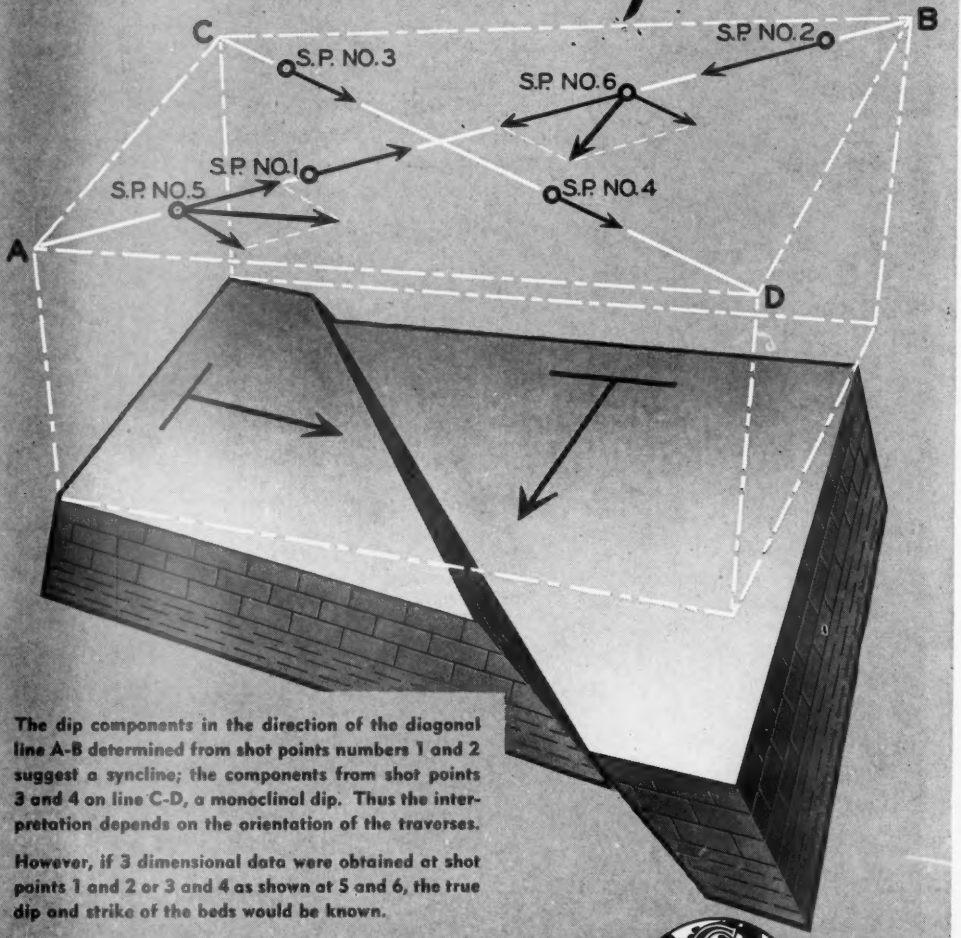
# Why 3 Dimensional Shooting is Necessary




The dip components in the direction of the diagonal line A-B determined from shot points numbers 1 and 2 suggest a syncline; the components from shot points 3 and 4 on line C-D, a monoclinal dip. Thus the interpretation depends on the orientation of the traverses.

However, if 3 dimensional data were obtained at shot points 1 and 2 or 3 and 4 as shown at 5 and 6, the true dip and strike of the beds would be known.

SSC's three dimensional shooting technique is necessary in faulted areas for the ACCURATE REVEALING OF GEOLOGIC STRUCTURE.

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*of the*

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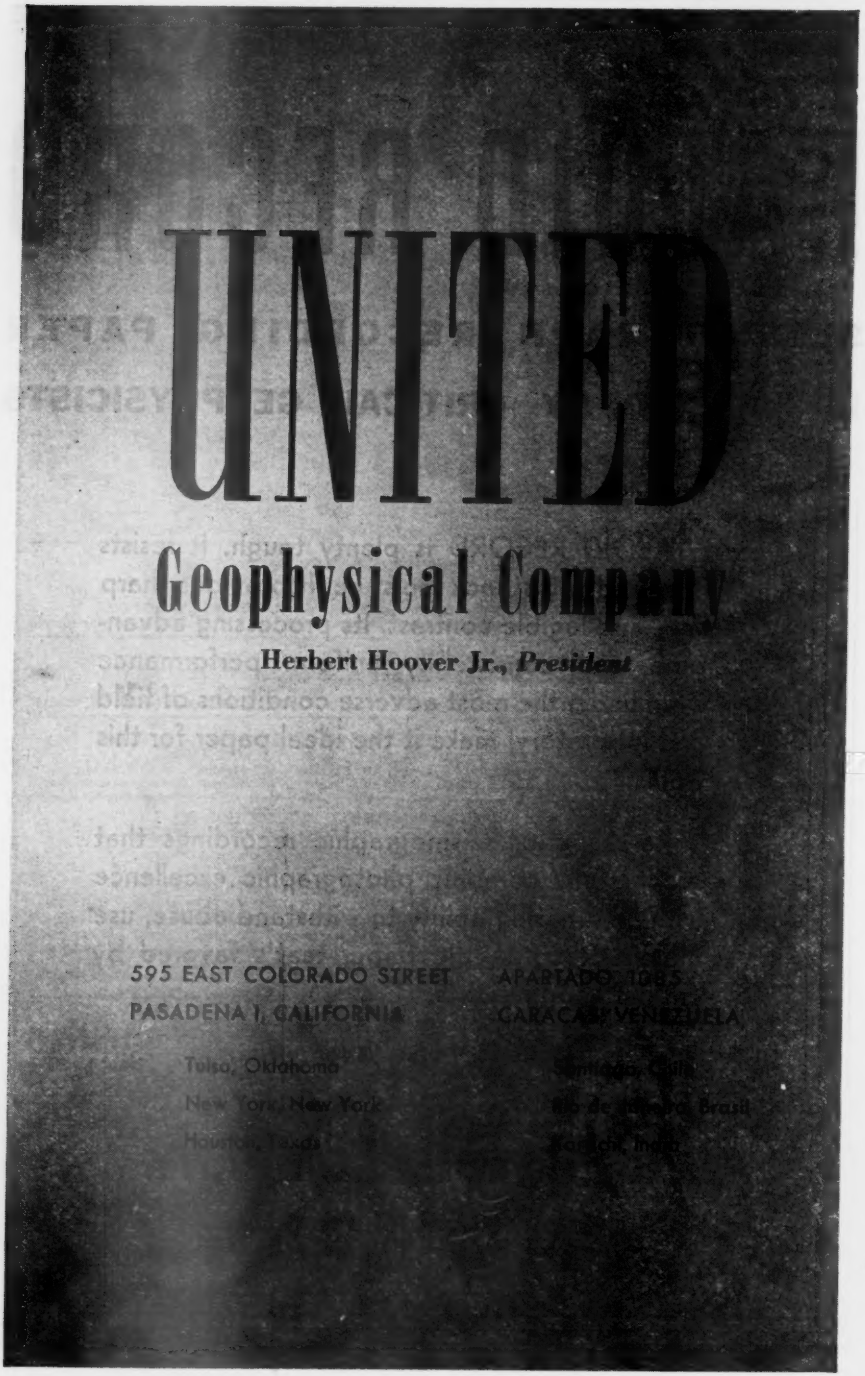
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Thank God for watchful care,
For health and all the food we eat
And for the clothes we wear.
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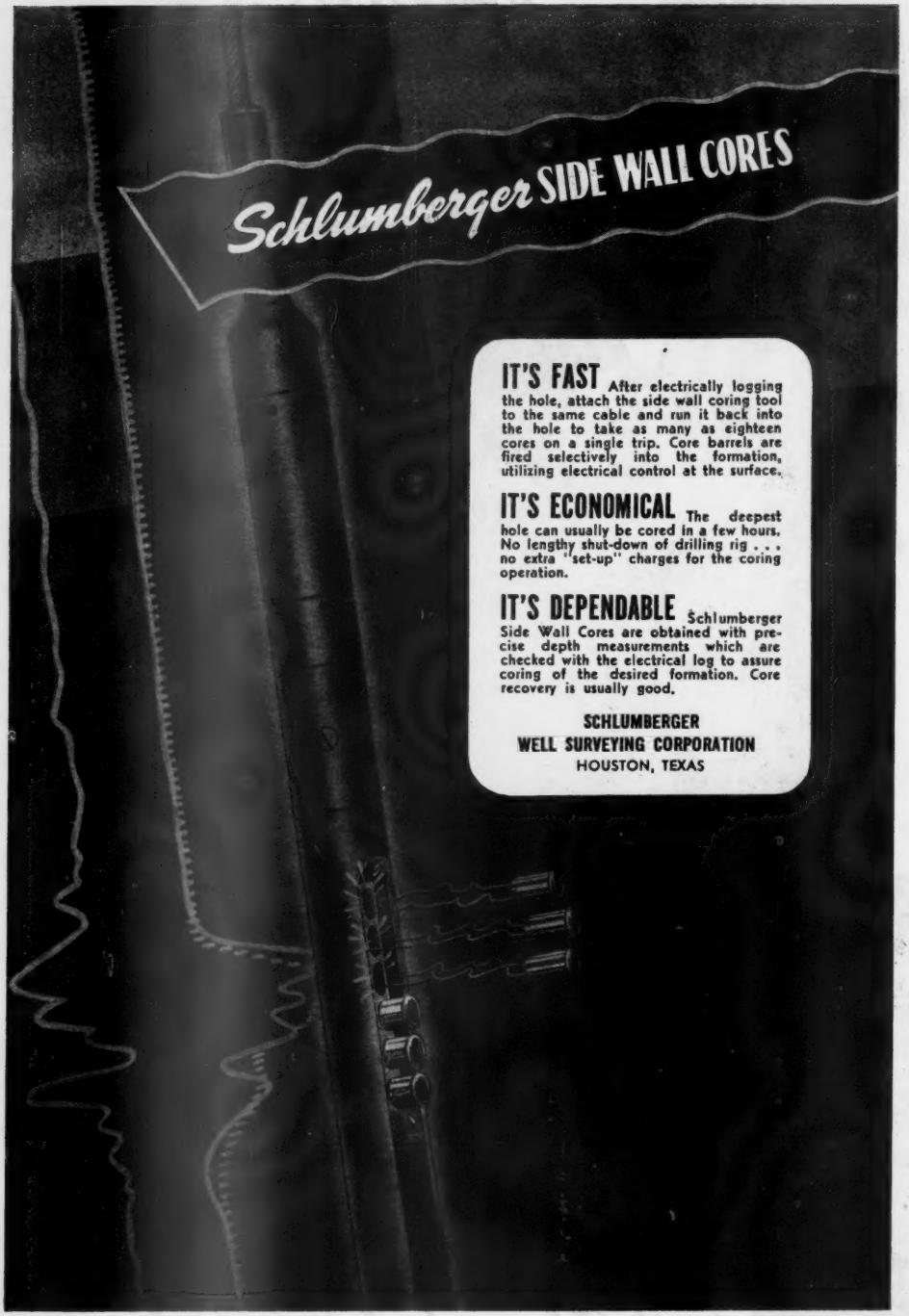
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# Articles for December *Bulletin*

**Oil Fields of Greater Oficina Area, Central Anzoategui, Venezuela**
By H. D. Hedberg, L. C. Sass, and H. J. Funkhouser

**Oil Fields of West Buchivacoa, Venezuela** By G. W. Halse

**El Mene de Acosta Field, Venezuela** By H. H. Suter

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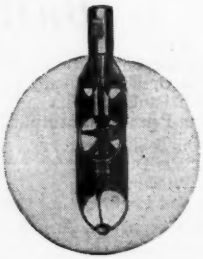
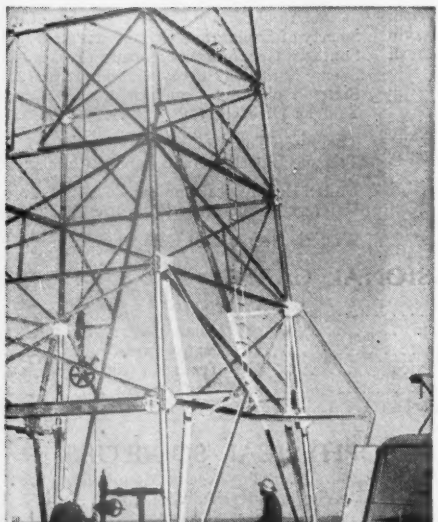
*FLOW RATE INDICATOR*

For produced or injected fluids in your well.



*Dowell Spinner surveys—chart subsurface fluid flow*



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**GAS WELL EXAMPLE:**

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# ORIGIN AND MIGRATION OF OIL INTO SESPE REDBEDS, CALIFORNIA[1]

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## ABSTRACT

The name "Sespe formation" is applied to the non-marine redbed facies of a group of sedimentary rocks up to 7,500 feet thick that range in age from upper Eocene into lower Miocene in the southern and eastern parts of the Ventura basin, California, but are probably restricted to the Oligocene in most of the northern and western part of the basin.

The lower part of the Sespe becomes progressively marine westward beginning about 25 miles west of Santa Barbara, but this marine Oligocene is mainly sandstone or silty shale, low in organic material that does not suggest a source rock.

The bulk of the evidence, which is discussed in detail, suggests that the larger part of the oil was derived from Eocene shales. Vertical migration across the bedding of several hundred to a few thousand feet of predominantly sandy strata seems to be required. Countless minor joints and cracks in the shaly interbeds are suggested as the principal channels of vertical migration. In the southeastern part of the Ventura basin some of the oil may have reached the lower, or Eocene part of the Sespe by lateral migration from upper Eocene shales, into which the lower Sespe may grade, followed by upward migration within the anticlines to the shalier middle Sespe, where most of it is trapped.

## INTRODUCTION

The name "Sespe formation" is applied to the redbed, continental facies of an important group of sedimentary rocks that are widely distributed in the Ventura basin of southern California. In the eastern part of the basin the Sespe includes strata that range in age from upper Eocene through Oligocene into lower Miocene, but in the western part it is apparently restricted to the Oligocene. It is one of the most important oil-producing non-marine formations in California.

This paper is divided into two parts, one factual and the second largely speculative or inferential: (I) the stratigraphic and age relations of the Sespe and adjacent strata, and (II) the origin of Sespe oil and how it reached its present reservoirs.

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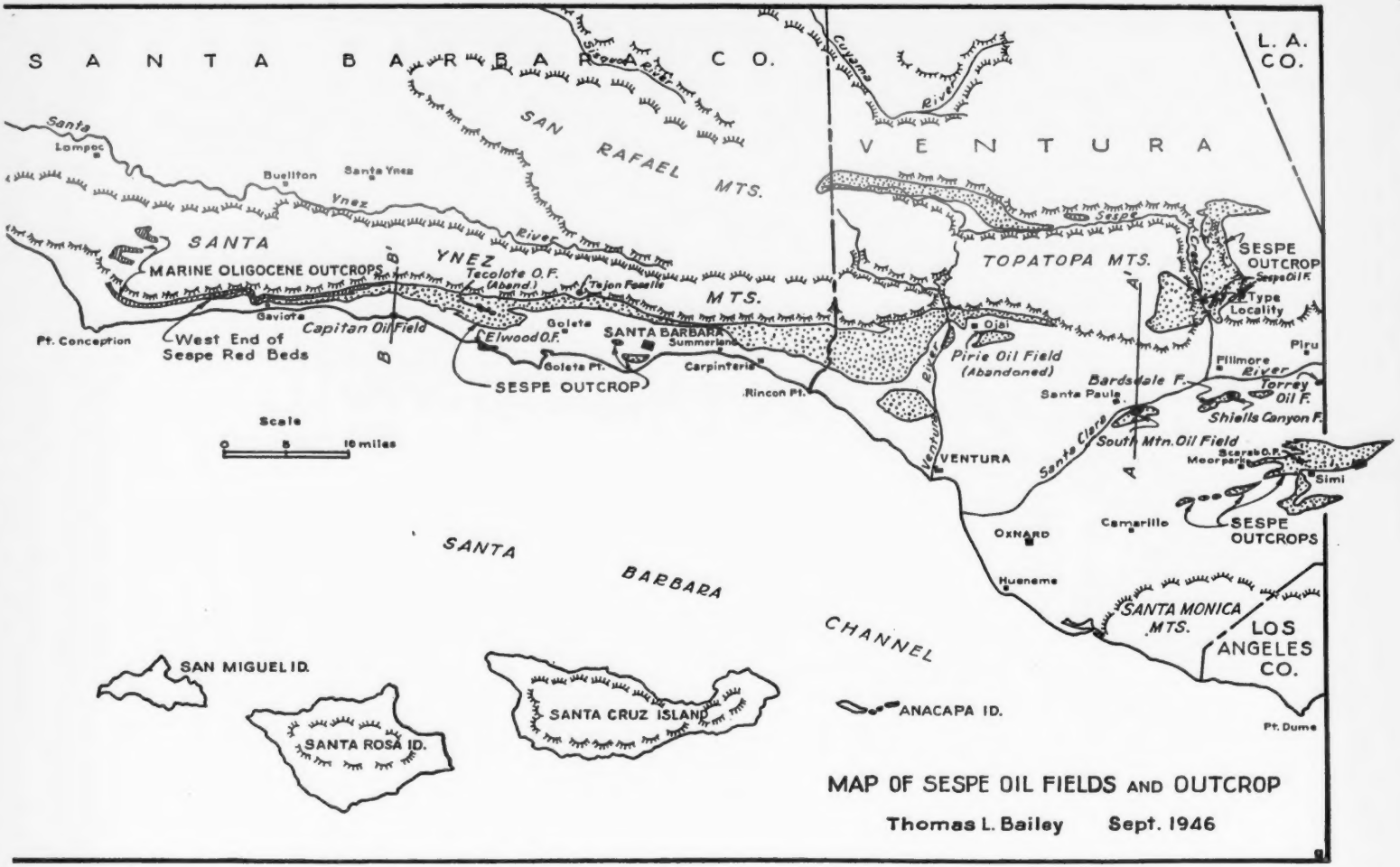

SANTA BARBARA CO.
L. A. CO.
VENTURA
SAN RAFAEL MTS.
Santa Lompoc
Buellton
Santa Ynez
Ynez River
SANTA YNEZ MTS.
MARINE OLIGOCENE OUTCROPS
Tecolote O.F. (Aband.)
Tejon Fossils
Gaviota
Capitan Oil Field
Pt. Conception
West End of Sespe Red Beds
Goleta
Elwood O.F.
SANTA BARBARA
Summerland
Goleta Pt.
Carpinteria
SESPE OUTCROP
Rincon Pt.
Scale
0 5 10 miles
Cuyama River
Sespe
TOPATOPA MTS.
SESPE OUTCROP
Sespe Oil F.
Type Locality
Ojai
Pirie Oil Field (Abandoned)
Piru
Fillmore
Bardsdale F.
Santa Paula
Torrey Oil F.
Shiells Canyon F.
Ventura River
Santa Clara River
South Mtn. Oil Field
Scarab O.F.
Meiners
Simi
VENTURA
OXNARD
Camarillo
SESPE OUTCROPS
Hueneme
SANTA BARBARA CHANNEL
SANTA MONICA MTS.
LOS ANGELES CO.
Pt. Dume
SAN MIGUEL ID.
SANTA ROSA ID.
SANTA CRUZ ISLAND
ANACAPA ID.
MAP OF SESPE OIL FIELDS AND OUTCROP
Thomas L. Bailey Sept. 1946

FIG. 1

### I. STRATIGRAPHIC AND AGE RELATIONS OF SESPE

This part summarizes for the reader who is not familiar with it, the significant features concerning the Sespe and its relations to adjacent strata. Reed[3] gives a good summary of the formation in his *Geology of California.*

*Distribution.*—The belt of outcrop of the Sespe is at least 100 miles long, being definitely recognized from a point 10 miles east of Pt. Concepcion, Santa Barbara County, eastward to a few miles east of Simi, Ventura County, as shown in Figure 1. Outcrops of probable Sespe have been mapped another 15 to 25 miles farther east near the head of the Santa Clara River in northern Los Angeles County. It has been doubtfully identified in the eastern Santa Monica Mountains, in the south end of the San Joaquin Valley, in the Cuyama Valley, at the west end of the Santa Ana Mountains, and, in the subsurface, in the eastern part of the Los Angeles basin as far west as the West Coyote oil field. The Lospe redbeds of the Santa Maria basin may be approximately equivalent and these have yielded a little commercial production in one or two wells in the Casmalia Hills. However, the only important Sespe oil production at present is in the Ventura basin, which lies between the crest of the Santa Ynez-Topatopa Mountains on the north and the Santa Monica Mountains and their westerly continuation, the Channel Islands, on the south. This paper is restricted to the Ventura basin. The type locality of the Sespe is on lower Sespe Creek about 6 miles north of Fillmore (eastern part of Figure 1).

*Description.*—North of the Santa Clara River, which approximately follows the axis of the Ventura basin, the Sespe is predominantly red or maroon in color. It consists of coarse to fine arkosic, ferruginous sandstones, more or less silty shales or massive mudstones, some of which are mottled with grayish green; and poorly sorted sandy conglomerates, some of which contain good-sized cobbles as well as pebbles. Conglomerates comprise most of the lower 500 feet of Sespe a few miles west of Ojai. Farther west between Rincon Creek and the San Marcos Pass Road, north of Goleta, the lower 500 feet or so is mostly pink to whitish, massive, medium to coarse sandstone. West of Santa Barbara in the upper 1,000 feet of Sespe, light gray or pinkish, buff-weathering arkosic sandstones begin to appear and increase westward. The middle part is still red and is composed mainly of fine sandstones and shales or mudstones, many of which are mottled with green or yellow. West of the abandoned Tecolote oil field (Fig. 1) most of the Sespe sandstones become gray or pinkish and weather buff, only the fine sandstones and argillaceous beds are still red. Two or three miles northwest of the Capitan oil field, marine fossils begin to appear in the buff-weathering sandstones near the base of the Sespe and finally, north of Santa Anita Station, which is about 10 miles east-northeast of Pt. Concepcion, the Sespe redbed facies wedges out completely between the marine Vaqueros above and the marine Oligocene (lower Sespe equivalent) below.

[3] Ralph D. Reed, *Geology of California,* Amer. Assoc. Petrol. Geol. (Tulsa, 1933), pp. 147–62.

In more detail, this wedging-out of Sespe redbeds takes place as here described. From a point a few miles east of the Ventura County line westward nearly to Pt. Concepcion is a persistent bed or zone of purplish red conglomerate 5 to 50 feet thick. It is composed mainly of angular pebbles of Franciscan red and green chert and contains numerous eroded and fragmentary oysters derived from the upper Eocene below. This conglomerate is a good marker occurring 600–800 feet above the base of the Sespe. It indicates some erosion of the upper Eocene on the north during the deposition of this conglomerate. Within a distance of only 5 miles westward from Tajiguas Canyon (3 miles west of cross section *BB'*) where the first marine beds begin to interfinger with the lower Sespe, all the 600 feet or so of lower Sespe between this marker conglomerate and the base of the Sespe lose their red color entirely and become marine; the conglomerate is at the base of the Sespe redbeds all the way to Santa Anita Canyon (10 miles northeast of Pt. Concepcion) where it is overlapped and truncated by the Vaqueros sandstone. Only the lower 600–800 feet of Sespe below this conglomerate were actually traced into marine sandstones and silty shales by Leslie M. Clark and the writer in 1929–1930. The rest of the Sespe above is overlapped and covered by the Vaqueros. This is shown by the surface mapping and by the fact that more than 300 feet of greenish gray and pink sandstones and red and green silty shales were penetrated below the Vaqueros in wells on the coast near Santa Anita Station about a mile south of the point where the Sespe wedges out on the outcrop. In another well a mile east of Pt. Concepcion (about 9 miles farther west) no redbeds were encountered although the well was drilled far into the Eocene (into Matilija sandstone or lower).

South of the Santa Clara River, in the rectangular area between the towns of Simi, Camarillo, Santa Paula, and Piru, and vicinity, the sandstones and sandy conglomerates are mainly buff-weathering, light gray, greenish gray or pinkish in color, only the shales, claystones, and sandy siltstones are commonly red in color and many of them are green or green and red mottled. As in most of the Sespe, the sandstones are high in feldspar, and biotite is common to abundant. The conglomerates in this southeastern part of the Ventura basin contain many granitic and gneissic pebbles that are probably derived from the Tehachapi-San Emigdio and northern San Gabriel Mountain region on the north and east. In general appearance the Sespe south of the Santa Clara resembles that on the south flank of the Santa Ynez Mountains between Goleta and Gaviota, except that no marine intercalations are found in Ventura County. In fact most of the Sespe land vertebrate fossils have been collected in this southeasterly area.

*Variation in age of Sespe from east to west.*—The variation in age of the sediments included in the Sespe from east to west is shown graphically in Figure 2. Beginning at the east, a few miles northwest of Simi, the lower part of the Sespe (1,600 to 3,000 feet above the top of the marine middle Eocene) contains a fairly large vertebrate fauna consisting of rhinoceros, camels, titanotheres, rodents,

*et cetera*. Chester Stock[4] has determined this fauna as upper Eocene (Uinta of Rocky Mountains). At Las Posas Hills, about 10 miles southwest of Simi, Stock[5] and associates collected an upper Oligocene (upper White River of the Nebraska-Dakota Great Plains) vertebrate fauna containing a small sabertooth tiger, rhinoceros, tortoise, *et cetera*, from Sespe redbeds about 500 feet below the base of the unconformably overlying middle Miocene and 2,500–3,000 feet above the top of the marine Eocene, as determined from cores in a near-by well. Except for a few hundred feet of basal upper Eocene with Tejon fossils in well cores this marine Eocene is middle Eocene also. At the outcrop in and near the South Mountain oil field Stock[6] found two zones of mammalian bones: (1) an Oreodon zone of lower Miocene age, 800 to 1,100 feet below the top of Sespe and (2) a Leptauchenid zone, probably upper Oligocene in age, 1,200–2,000 feet below the top of the Sespe. These two zones at South Mountain are between 6,200 and 5,000 feet above the top of the marine Eocene (probably mainly middle Eocene) penetrated in wells at South Mountain.

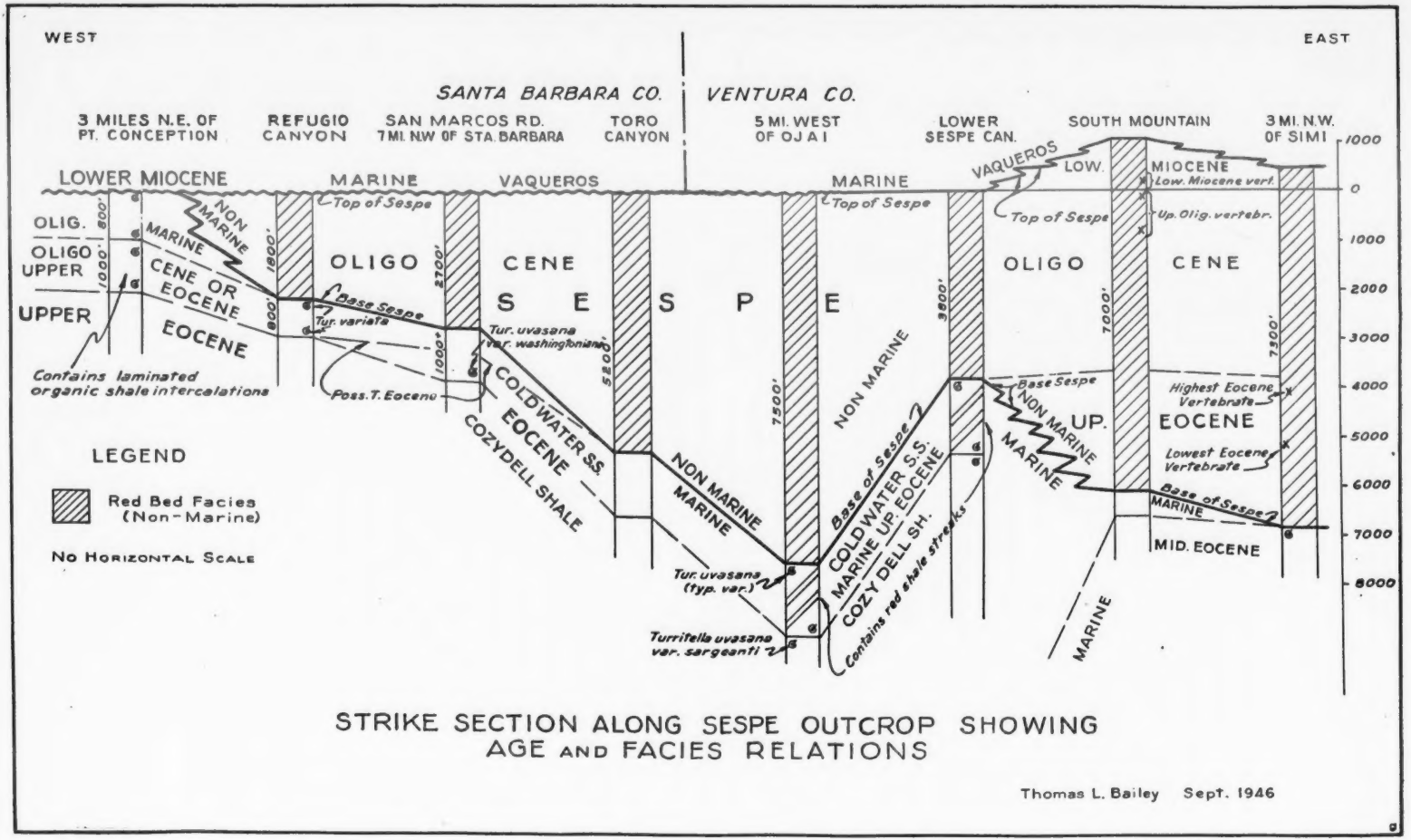
On the basis of this excellent vertebrate evidence, the Sespe south of the Santa Clara River includes beds ranging from upper Eocene to lower Miocene inclusive. At Las Posas Hills where much of the upper Sespe has been truncated by the middle Miocene, it is improbable that any of the Sespe is lower Miocene.

In view of the fact that the Sespe north of the Santa Clara River between Fillmore and Pt. Concepcion rests on the Coldwater sandstone, which is the highest formation in a very thick (4,000–8,000 feet) upper Eocene group, it is improbable that it includes much if any Eocene. North of Fillmore where the Sespe is conformable with the Vaqueros above, it may include a little lower Miocene. However, from the Ojai Valley westward the Sespe-Vaqueros contact is very sharp and generally disconformable; near the mouth of Lion Canyon, 2 miles south of Ojai, a difference in strike of 20° or more was indicated by mapping. In an outcrop of the contact in a small road cut 2 miles southeast of Ojai on the Camp Comfort Road, the contact is also distinctly irregular, the strike is different above and below the contact, and clam burrows filled with Vaqueros sand extend several inches down into the Sespe. However, the top of the Sespe seems to be only a slight unconformity or disconformity in most places where it was observed between the Ventura River and Summerland. Between Capitan Canyon (section *BB'*, Fig. 1) and Pt. Concepcion, there is a slight but distinct difference in strike and dip between the Sespe and the overlying lower Miocene (Vaqueros) whereby the upper half or more of the Sespe becomes gradually truncated and

[4] Chester Stock, "Eocene Land Mammals on the Pacific Coast," *Proc. Nat. Acad. Sci.*, Vol. 18, No. 7 (1932), pp. 518–23.

[5] *Idem*, "An Upper Oligocene Mammalian Fauna from Southern California," *ibid.*, Vol. 18, No. 8 (1932), pp. 550–54.

[6] *Idem*, "Oreodonts from the Sespe Deposits of South Mountain, Ventura County, California," *Carnegie Inst. Washington Pub. 404* (1930), pp. 27–41.




STRIKE SECTION ALONG SESPE OUTCROP SHOWING AGE AND FACIES RELATIONS

Thomas L. Bailey Sept. 1946

FIG. 2

overlapped by the Vaqueros westward. For these reasons the Sespe north of the Santa Clara River is considered to be mostly or entirely restricted to the Oligocene.

*Thickness and stratigraphic relations of Sespe.*—The Sespe ranges in thickness from 0, near Pt. Concepcion, to 7,500 feet near Ojai as shown in Fig. 2. It is 7,400 feet thick northwest of Simi but includes there most or all of the upper Eocene; at Los Posas Hills at the southwest it is only 3,000 or 4,000 feet thick, but a local unconformity or disconformity observed in a core of the contact in Shell Oil Company's Everett well No. 1 has apparently removed much of the upper Eocene so that little if any Eocene is included in the Sespe here. However, farther northwest at South Mountain it thickens to 7,000 feet and probably includes some upper Eocene, although gray Eocene shale pebbles in lower Sespe may indicate that some upper Eocene was eroded in pre-Sespe time. At the type locality north of Fillmore the Sespe is only 3,800–4,000 feet thick, but it thickens in a short distance westward, culminating in a 7,500-foot section at the Ventura River west of Ojai. From the Ojai Valley it thins gradually to about 6,000 feet at the Ventura-Santa Barbara County line and 5,200 feet in Toro Canyon, northeast of Summerland. West of Santa Barbara it thins more markedly to 2,700 feet at the San Marcos Pass road north of Goleta, 1,800 feet in Refugio Canyon, 1½ miles northwest of the Capitan field, 600 feet in Gaviota Canyon where the lower half of the original Sespe has become marine and finally disappears beneath the lower Miocene a few miles east of Pt. Concepcion, as already mentioned.

FIG. 2

The axis of maximum Sespe sedimentation extends from a point a few miles north of Simi west-northwestward through South Mountain and a point about 3 miles south of Ojai to a mile or so north of Carpinteria. Thence it trends nearly due west through Santa Barbara and Goleta to the Capitan field; from there it passes into the ocean and extends westward to a point a short distance offshore from Santa Anita Station near Pt. Concepcion. This is supported by the following evidence.

1. On lower Sespe Creek north of the axis of sedimentation the Sespe formation is only 4,000 feet thick or less and much thinner on upper Sespe Creek at the northwest. This is comparable with 7,000 feet or more at South Mountain and northwest of Simi. South of this maximum it thins to 3,500–4,000 feet at Los Posas Hills, a few miles east of Camarillo.

2. At Red Mountain, 10 miles southwest of Ojai, where the base has been penetrated at 2,300 to 3,000 feet in wells, the Sespe is only 3,700–4,000 feet thick as compared with 7,500 feet 6 or 7 miles north.

3. At Elwood oil field Mason Hill[7] gives the Sespe thickness as 2,500 feet and states that it is thinner than at the outcrop. It is only 2,400 feet thick in LaGoleta gas field,[8] south of Goleta, as compared with 2,700 feet at the outcrop at the north.

[7] Mason L. Hill, "Elwood Oil Field," *California Dept. Nat. Res. Div. of Mines Bull. 118* (1943), pp. 380–83.

[8] R. O. Swayze, "LaGoleta Gas Field," *ibid.*, p. 384.

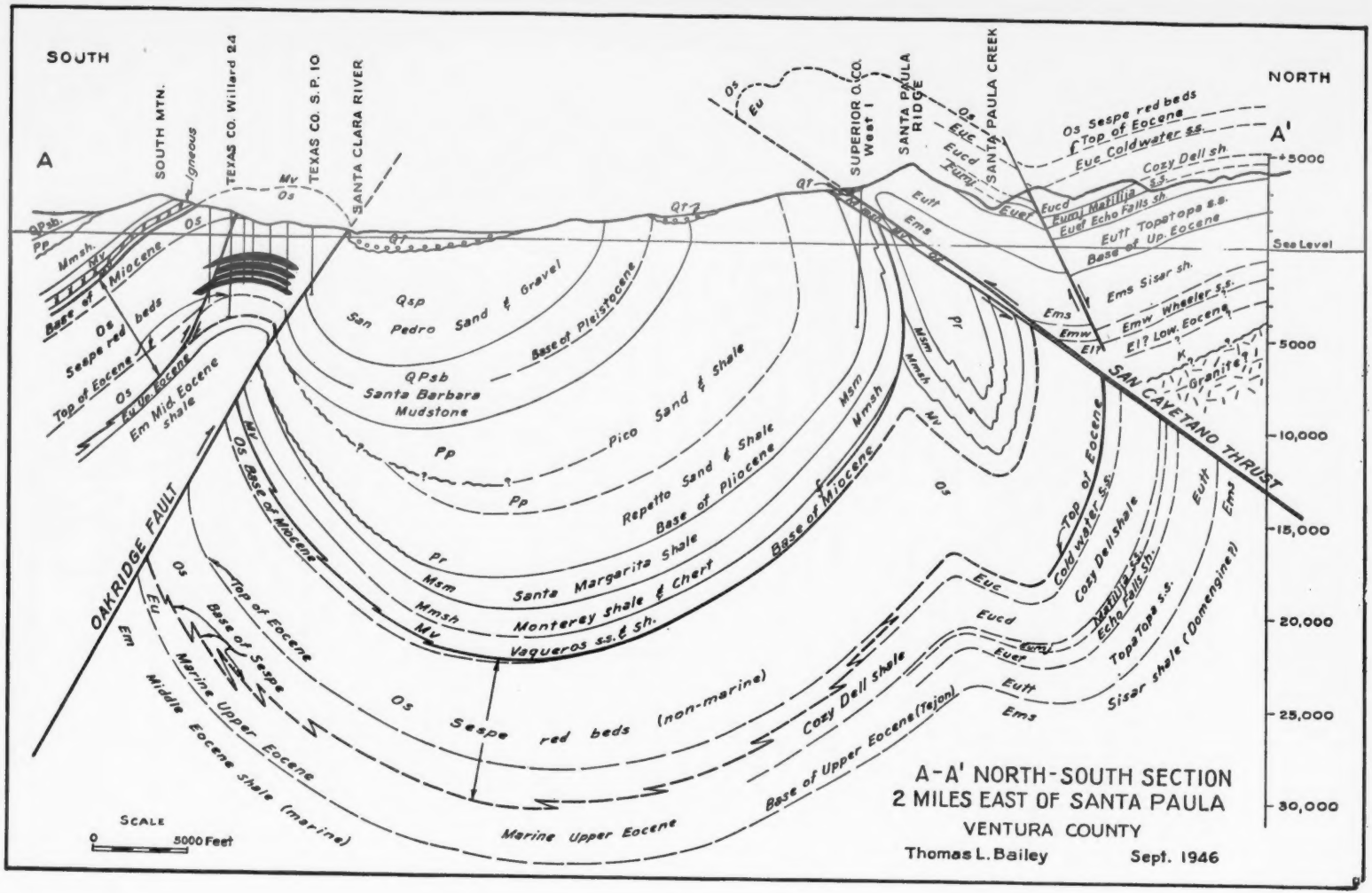

SOUTH
NORTH
A
A'
SOUTH MTN.
Igneous
TEXAS CO. Willard 2-4
TEXAS CO. S.P. 10
SANTA CLARA RIVER
SUPERIOR O.CO. West 1
SANTA PAULA RIDGE
SANTA PAULA CREEK
Os Sespe red beds
Top of Eocene
Eue Coldwater ss.
Cozy Dell sh.
Euf Echo Falls sh.
Eutf Topatopa s.s.
Base of Up. Eocene
Ems Sisar sh.
Emw Wheeler s.s.
El? Low. Eocene
Granite
Sea Level
+5000
5000
10,000
15,000
20,000
25,000
30,000
Base of Miocene
Os Sespe red beds
Top of Eocene
Os Eu Em Mid. Eocene shale
Base of Pleistocene
Qsp San Pedro Sand & Gravel
QPsb Santa Barbara Mudstone
Pp Pico Sand & Shale
Repetto Sand & Shale
Base of Pliocene
Pr
Msm Santa Margarita Shale
Mmsh Monterey Shale & Chert
Mv Vaqueros ss. & Sh.
OAKRIDGE FAULT
Os Base of Miocene
Top of Eocene
Os Base of Sespe
Eu Em Middle Marine Upper Eocene Shale (marine)
Os Sespe red beds (non-marine)
Marine Upper Eocene
Base of Upper Eocene (Tejon)
Cozy Dell shale
Sisar shale (Domengine?)
SAN CAYETANO THRUST
Top of Eocene
Cold water ss.
Cozy Dell shale
Topatopa ss.
Echo Falls sh.
SCALE
0 5000 Feet
A-A' NORTH-SOUTH SECTION
2 MILES EAST OF SANTA PAULA
VENTURA COUNTY
Thomas L. Bailey
Sept. 1946

FIG. 3

4. At Capitan oil field it is 2,300 feet thick, as compared with only 1,800 feet at the outcrop (Fig. 4).

*History of Sespe sedimentation.*—The Sespe accumulated in an elongate east-west subsiding basin or wide flat-bottomed continental valley trending a little more southeasterly than the present axis of the Ventura basin. Into this continental, coastal plain basin shorter southward- and northward-flowing streams probably joined a larger westward-flowing river and together dumped great quantities of clastic débris which had a prevailing red color. (This color is probably due to the development of lateritic clay soil under the prevailing tropical climate.)

*Tehachapi-San Emigdio Mountains.*—Another mountain mass composed largely of Franciscan rocks extended a 100 miles or so, probably near the present San Rafael Mountains and northwesterly. This large Oligocene mountain mass separated the Sespe non-marine basin from the Kreyenhagen marine basin farther north. (The axis of the Kreyenhagen basin is apparently toward the west edge of the present San Joaquin Valley.) Franciscan cherts must have been extensively exposed in these ancient mountains in the area north of the present Ojai Valley and westward because pebbles of red and green chert are abundant in certain parts of the Sespe as well as the Vaqueros sandstone between Ojai Valley and Gaviota Canyon.

FIG. 3

At the east end of the Sespe basin an elevated landmass may have existed near the site of the present San Gabriel Mountains. It may have contributed some or much of the granitic débris that comprises such a large part of the Sespe south of the Santa Clara River. However, the prevalence of granitic and gneissic pebbles 6 inches (15 centimeters) in diameter or larger and the great abundance of fresh biotite in the sandstones and siltstones in the Oak Ridge-Simi region suggests a nearer source such as the Santa Monica Mountain block at the southeast, where granitic rocks underlie the Miocene near Cahuenga Pass and eastward. The Santa Monica Mountains-Simi Hills-Channel Island block or blocks on which the upper Eocene (Tejon) is generally missing were evidently elevated and constituted the southern boundary of the Sespe basin.

As most of the Sespe oil-field waters are highly saline the Sespe basin must have been enclosed or semi-enclosed, but the climate was not dry enough or the basin was not sufficiently land-locked to cause gypsum and salt precipitation, although some thin lenticular lacustrine limestone beds are noted in the Sespe. The abundance of fresh feldspar and biotite, as well as the salt water in the Sespe, suggests semi-arid conditions at the site of deposition. On the other hand, the decomposition of most of the ferro-magnesian minerals into red oxides of iron, especially in the northern part of the basin, and the presence of a varied vertebrate fauna requiring plenty of vegetation, at least along the streams, indicate that the climate was not really arid.

The Sespe basin of deposition had already risen above the sea in the Simi region in upper Eocene time while at least the upper half of a 5,000- to 8,500-foot

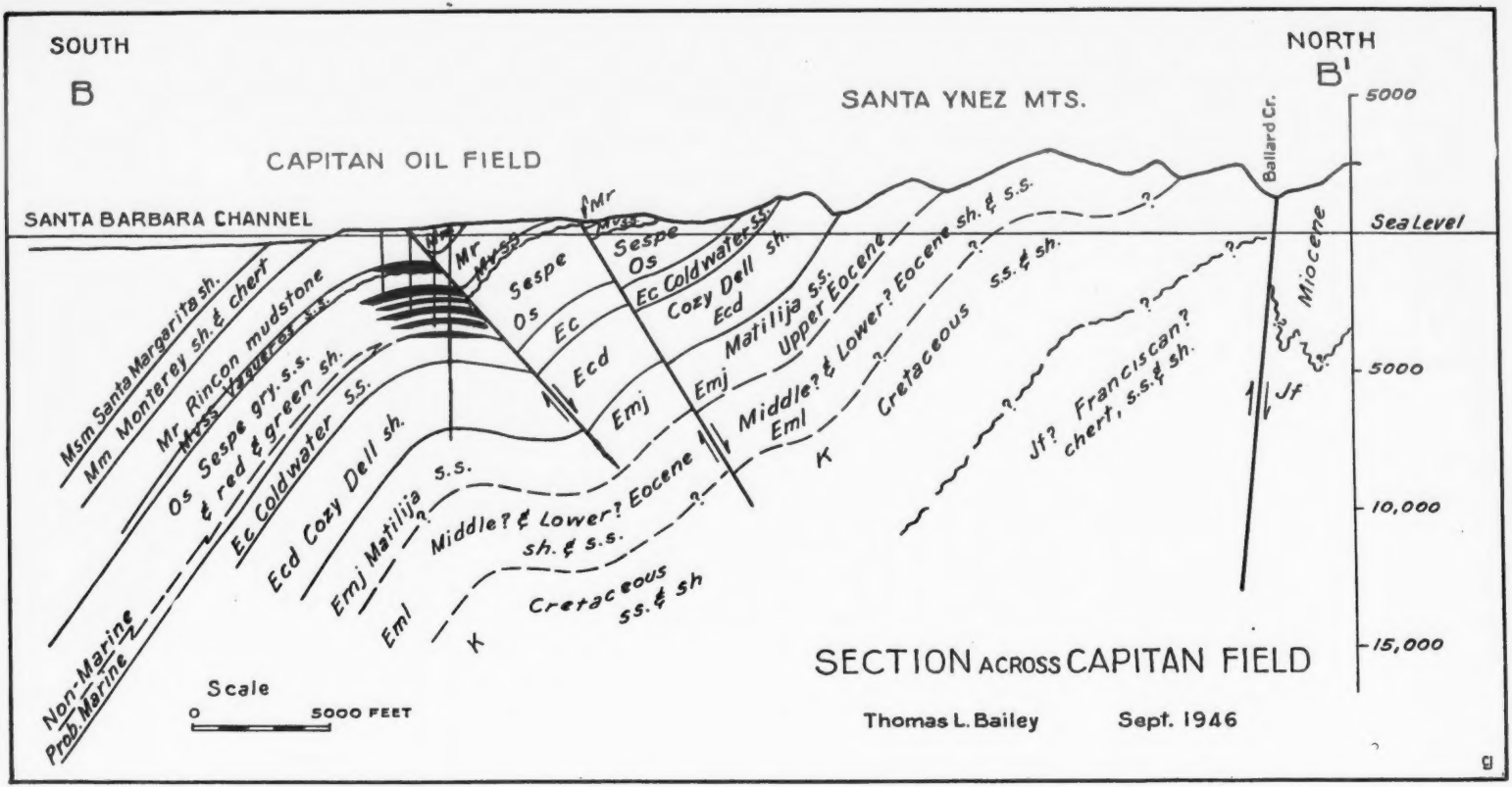

SOUTH
B
NORTH
B'
SANTA YNEZ MTS.
CAPITAN OIL FIELD
SANTA BARBARA CHANNEL
Ballard Cr.
Sea Level
5000
5000
10,000
15,000
Msm Santa Margarita sh.
Mm Monterey sh. & chert
Mr Rincon mudstone
Mr ss. Vaqueros ss.
Os Sespe gry. s.s. & red & green sh.
Ec Coldwater ss.
Ecd Cozy Dell sh.
Emj Matilija s.s.
Eml Middle? & Lower? Eocene sh. & s.s.
K Cretaceous ss. & sh
Non-Marine
Prob. Marine
Sespe
Os
Ec
Ecd
Emj
Eml
Ec Coldwater ss.
Cozy Dell sh.
Matilija s.s.
Upper Eocene
Middle? & Lower? Eocene sh. & s.s.
Cretaceous ss. & sh.
Miocene
Jf
Jf? Franciscan? chert, s.s. & sh.
Scale
0 5000 FEET
SECTION ACROSS CAPITAN FIELD
Thomas L. Bailey Sept. 1946

FIG. 4

section of marine upper Eocene (Tejon) sands and muds were accumulating in a narrow geosyncline on and near the site of the present Santa Ynez-Topatopa Mountains. Los Posas Hills between Simi and Camarillo may have been somewhat elevated so that little upper Eocene was deposited on them, but some of the upper Eocene was eroded about the end of Eocene time. These hills were evidently a peninsula extending westward from the Simi Hills uplift, south of Simi. In Tejon time the southern boundary of the basin was a mountain mass somewhere near the present Santa Monica Mountains and Channel Islands or farther south, so that a 100-mile long, trough-like, eastward-pointing marine embayment existed near the present Santa Ynez-Topatopa Mountains[9] in Tejon time. The lower 3,000 feet of Sespe, which are apparently of Tejon age in the Simi region and probably in the Oak Ridge-South Mountain area as well, were being deposited on a coastal plain bordering this marine embayment on the south while the thick marine upper Eocene (Tejon) was accumulating in the sea on the north.

About the beginning of Oligocene time the upper Eocene embayment had become filled above sea-level except at the west end (west of the Capitan field). During the Oligocene the sea gradually withdrew westward—almost to Pt. Concepcion in middle or late Oligocene time and beyond Pt. Concepcion prior to Vaqueros deposition.

In lower Miocene (Vaqueros) time, however, the redbed continental deposition continued in the southeastern part of the Ventura basin until mid-Vaqueros or later lower Miocene time. The Vaqueros sea evidently started flooding the land from the west and transgressed eastward during the lower Miocene. In the Simi Hills-Las Posas Hills region gentle folding raised the newly deposited Sespe and removed the upper 500 feet or more of it. This was followed by general submergence and advance of the Miocene sea over the whole Ventura basin by middle Miocene.

### MARINE OLIGOCENE

The gradual transition of the lower 600 to 800 feet of Sespe into marine beds between section *BB'* and Pt. Concepcion has already been described.

These marine Oligocene beds consist mainly of well indurated, buff-weathering, gray, fine- to coarse-grained, somewhat feldspathic sandstone of similar appearance to the upper Eocene sandstone below. Subordinate gray or greenish gray silty shales are interbedded with the sandstone and become fairly prominent at the extreme west, between Point Concepcion and Lompoc. There may be more marine Oligocene south of Lompoc than that shown on the map but it is difficult to distinguish lithologically from the upper Eocene. *Acila shumardi*, *Macrocallista pittsburgensis*, and *Lima oakvillensis* which are restricted to the Oligocene by many paleontologists, as well as *Turritella variata* and *Crassatella collina* which are

[9] Because of at least 2 or 3 miles of southward shift of the Topatopa Mountains in Pleistocene time, along the San Cayetano thrust, the axis of this basin was a few miles north of the crest of these mountains.

also found in the upper Eocene (Coldwater sandstone), characterize this marine fauna. In Jolloru Canyon south of Lompoc, considerable lamellar shale and at least two thin beds of whitish-weathering, regularly laminated and banded, foraminiferal organic shale and shaly limestone were noted. These 2- to 4-inch beds resemble some of the Kreyenhagen shale of Oligocene-Eocene age which is generally considered to be an oil source rock in the San Joaquin Valley. However, most of the marine Oligocene shale is sandy and low in organic traces; it does not look like an important source rock. As no definite Oligocene has been recognized in the Channel Islands at the south it is not known whether[9a] the marine Oligocene becomes rich enough to be a source sediment for oil farther south off the coast. However, judged from what can be seen of it, the Oligocene becomes marine toward the west rather than toward the south.

### COLDWATER SANDSTONE PROBLEM

At the type locality on Coldwater Creek, a westerly branch of lower Sespe Creek, $5\frac{1}{2}$ miles northwest of Fillmore, this uppermost formation of the Tejon group consists mainly of white to pinkish massive, arkosic sandstone with intercalations of maroon, purplish, and dark green mudstones.

Kew[10] reports it is 350 to 750 feet thick in the Sespe Creek region and that it is slightly unconformable beneath the Sespe. The unconformity is doubtful and dies out a few miles west as the Coldwater formation thickens. The white and pink sandstones and maroon shales up to 50 feet thick continue westward a little beyond San Marcos Pass. However, the redbeds are subordinate west of Carpinteria Creek. In the Ojai region alternating pink standstones and maroon, purple, and greenish shales comprise about a third of the formation, occurring in two 400-foot thick members in the middle and lower parts of the 2,500-foot formation. Between San Marcos Pass and the Ventura River the Coldwater sandstone consists of 2,500–4,500 feet of hard, massive light gray to yellowish white, mostly medium-grained feldspathic sandstone. It generally contains many oyster beds up to 4 feet thick. West of San Marcos Pass the redbeds entirely disappear and the sandstone becomes darker gray, weathering buff; the interbedded thin shaly streaks are dark gray and the entire formation takes on the aspect of an ordinary marine sandstone.

The Coldwater is easily traceable between the red Sespe above and the black Cozy Dell shale below and has been traced by Leslie M. Clark and the writer from 8 miles east of Ojai, where it is cut out for a few miles by the San Cayetano thrust, almost to Pt. Concepcion where it breaks into alternating shales and sandstones. No indications of interfingering with formations above or below were observed, although the basal contact was not observed for 6 miles near San Marcos

[9a] Some redbeds between the marine lower Miocene and the marine Eocene have been reported on Santa Rosa Island. They are probably either Sespe (Oligocene) or Coldwater (upper Eocene).

[10] W. S. W. Kew, "Geology and Oil Resources of a Part of Los Angeles and Ventura Counties, California," *U. S. Geol. Survey Bull. 753* (1924), pp. 27–28.

Pass (Range 28 W.) where the Coldwater folds over the crest of the Santa Ynez range.

The Coldwater problem is the surprising change in the fauna of the Coldwater from a typical Tejon assemblage at San Marcos Pass and eastward into a fauna containing a number of species that are commonly considered Oligocene, the so-called Gaviota or *Turritella variata* fauna on the west.

The evidence follows.

1. At the mouth of Gridley and Sulphur Springs canyons, 2 miles northeast of Ojai, at the base of a greenish siltstone about 900 feet below the gradational contact between the Sespe and in the upper third of the Coldwater formation, the writer collected several fair specimens of *Turritella* which four well known paleontologists[11] in turn identified as Tejon Eocene (*Turritella uvasana*, typical variety, or close to it). The basal 135-foot sandstone of the Coldwater, ½ mile north, contains the same *Turritella* and several other Tejon species (*Psammobia hornii*, *Pecten calkinsi*, *Cardium brewerii*, and *Macrocallista conradiana*).

2. On the San Marcos Pass road, 500 feet north of the turn-off of the Painted Cave road and 1,000 feet or so below the base of the Sespe a number of fossils were collected in the Coldwater by Alex Clark and the writer. Alex Clark determined them as *Turritella uvasana* var. *washingtoniana*, *Pitar* cf. *uvasanus*, *Tellina lebecki*, and *Spisula bisculptura?* and stated that the fauna "seems to be all Tejon with none of the characteristic *Turitella variata* zone species present."

3. At 3,125 feet, about 580 feet below the base of the Sespe, in the Petroleum Exploration Company's McWilliams well No. 1, near the northern edge of the so-called "Mesa" and just west of the Santa Barbara city limits, *Turritella uvasana* cf. var. *sargeanti* and *Macrocallista conradiana* were cored. The same species of *Turritella* was cored as high as 2,653 feet, only 15 feet below the base of the Sespe in Carrey-Adams' Wright No. 1, located 4 miles northwest of Santa Barbara. This and the preceding evidence indicates a Tejon age for the Coldwater.

However, the following evidence seems to be opposed to a Tejon age and in favor of either uppermost Eocene (upper Jackson) or lower Oligocene for the Coldwater west of the Capitan field.

1. In Refugio Canyon just west of section *BB'*, *Turritella variata*, *Crassatella collina*, *Tivela inezana*, and other *Turritella variata* zone species were collected, both near the top and base of the Coldwater sandstone. These species are believed to be Oligocene by some paleontologists and uppermost Eocene by others.[12] They are common, along with *Acila shumardi* and other possibly more typical Oligocene species in the marine equivalent of the lower Sespe Oligocene on the west, between here and Lompoc.

As none of these Oligocene species has been found in the Coldwater east of

[11] Bruce L. Clark, H. G. Schenck, A. J. Tieje, and Alex Clark.

[12] W. P. Woodring, "Age of Orbitoid-Bearing Eocene Limestone and *Turritella variata* Zone of the Western Santa Ynez Range, California," *Trans. San Diego Soc. Nat. Hist.*, Vol. 6, No. 25 (1931), pp. 371–88.

San Marcos Pass, the Coldwater sandstone may become progressively younger toward the west from this pass, although this could not be detected in the mapping. The lower part of the Coldwater may change westward into shale like the Cozy Dell in the 6 miles around San Marcos Pass where the basal contact could not be traced. On the other hand, this may be a facies fauna that migrated from the west and has the same upper Eocene age as typical Coldwater sandstone. In Figure 2 is shown an alternate interpretation of the Eocene-Oligocene division line whereby the Coldwater of Refugio Canyon and westward is thrown into the Oligocene. In view of the reported occurrence of *Uvigerina cocoaensis*, an uppermost Eocene foraminifer, and the apparent continuity of the Coldwater sandstone east of San Marcos Pass where it is all Eocene, the writer prefers to include the entire Coldwater in the Eocene, although the *Turritella variata* zone Coldwater may be younger Eocene than type Tejon. All the marine beds that can be traced into the Sespe toward the east (Fig. 1) are retained in the Oligocene. The center of dispersal of the *Turritella variata* fauna must have been north and west of Pt. Concepcion so that it reached the western Santa Ynez Mountains slightly earlier than farther east. It is quite possible that the upper part of the Coldwater west of Santa Barbara gradually transgresses the theoretical top of Eocene time line by such small-scale interfingerings that it was not noted in mapping even on aerial photographs. Such an interfingering of Sespe redbeds with fossiliferous marine sandstones west of Tajiguas Canyon (mentioned previously) could be detected and was mapped but the marine equivalent to the lower part of the Sespe is mapped separately (Fig. 1) and is not included with the similar Coldwater sandstone.

Even if it is assumed, for the sake of argument, that the Coldwater west of Refugio Canyon is lower Oligocene and equivalent to some of the Sespe in the Ojai region, it does not help much with the origin of Sespe oil because the Coldwater is too low in organic material to yield much oil, except possibly in the Pt. Concepcion-Lompoc region where it becomes more shaly, but where no oil has been found in or near it to date.

## II. ORIGIN OF SESPE OIL AND ITS MIGRATION

In Part I the writer has attempted to assemble the known pertinent information on the Sespe and its relations to formations above and below in order to prepare the stage in the mind of the reader for the discussion of where the oil now stored in the Sespe came from and how it got there.

### OIL FIELDS WITH SESPE PRODUCTION

The fields that produce from the Sespe, or formerly produced from it but are now abandoned, are shown on the sketch map (Fig. 1).

The only important fields with Sespe production are two or three on the South Mountain-Oak Ridge anticlinal uplift south of Santa Paula and Fillmore and the Capitan field on a small faulted anticline about 20 miles west of Santa Barbara. The South Mountain field, with a cumulative production of 25 million barrels is

more than twice as productive as any of the others; Shiells Canyon with about 10 million barrels is second; Capitan is third with about 3 million barrels of Sespe oil and 8 million barrels of Vaqueros oil; Bardsdale with 4 or 5 million barrels of Sespe oil is fourth. Torrey Canyon, Elwood, the Sespe Canyon field, consisting of five small pools on and near Lower Sespe Creek, and possibly the west end of the Simi or Tapo Canyon field,[13] 4 miles northeast of Simi, have probably produced between 1 and 3 million barrels of oil from the Sespe. Elwood has produced more than 75 million barrels of oil, but only a small percentage[13a] of this has been from the Sespe, the great bulk of the production being Vaqueros Miocene. None of the other fields, including the abandoned Tecolote field north of Elwood and the Pirie field south of Ojai, has produced more than a few hundred thousand barrels.

### TYPE OF OIL IN SESPE REDBEDS

In the Ventura County fields, the gravity of the oil from Sespe reservoirs is mainly low to medium, ranging from 13° in one of the shallow fields in lower Sespe Canyon to 34° A.P.I. A little 38° gravity oil has been produced in one of the Sespe Canyon fields. Most of the Ventura County oil is 25° to 32° A.P.I.

The Santa Barbara County fields, including the abandoned Tecolote field, have yielded only high-gravity oil, 38° to 45° gravity; most of it is 40° to 42°. Most of this oil in both counties is high in gasoline and low in sulphur, which makes it a valuable crude.

A high paraffine content is commonly cited as a peculiarity of oil from the Sespe, suggesting a source different from the Miocene and Pliocene crudes. However, South Mountain oil with 2.25 per cent paraffine is lower than the Vaqueros oil at Elwood (2.9 per cent). Tecolote oil contained only 1.3 per cent paraffine and is lower than that from the upper Miocene at Lawndale with 1.9 per cent. The latter could hardly have a similar source because of the absence of pre-Miocene sedimentary rocks in that part of the Los Angeles basin, the Miocene resting directly on schists.

Some years ago the writer made a comparison of the distillation curves of certain Miocene and older California crudes in the hope that this might show some significant relationships but the results were inconclusive. Most of the curves were rather different from each other but three were similar, except for higher fractions (below 130° C.). These three similar distillation curves were Sespe oil from South Mountain, Vaqueros oil from Elwood and upper Miocene oil from Lawndale. The Sespe oil from Tecolote had a very dissimilar curve from South Mountain Sespe oil.

### STRATIGRAPHIC POSITION OF OIL MEASURES WITHIN SESPE

Starting at the southeast and going northwest, the oil in the Sespe in the Simi and Scarab fields is at or near the base of the upper Eocene part of the Sespe, less

[13] T. F. Stipp, "Simi Oil Field," *California Dept. Nat. Res. Div. of Mines Bull. 118* (1943), pp. 417–23.

[13a] Within the past year or so considerable Sespe oil has been produced by the Signal Oil and Gas Company from the western extension of Elwood, but the amount is not available.

than 1,000 feet above the marine middle Eocene (Domengine or Llajas) shales and siltstones. Sands in the middle Eocene have produced most of the oil (average 32° A.P.I.) in the Simi field.[14]

In the Oak Ridge fields, Shiells Canyon,[15] Bardsdale,[16] and South Mountain,[17] most of the production has been from sands in the lower part of the more shaly middle division of the Sespe from 1,500 to 2,700 feet above the top of marine Eocene. A little oil has been produced from the marine Eocene at Bardsdale. Figure 3 shows the structure and oil accumulation at South Mountain. Most of that in the Torrey Canyon field has been from the upper Sespe, some only 500 feet or less below the base of the marine Vaqueros, and extending down to 2,500 feet or so below the Vaqueros. (Only a little uppermost Sespe is exposed on the crest of the Torrey Canyon faulted dome; in the other Oak Ridge fields the upper 1,000–2,000 feet of Sespe is exposed and any accumulations high in the Sespe would have escaped.)

In the small Sespe Canyon[18] fields the oil has come from upper Sespe down into the Coldwater Eocene, but most of it is from the lower 2,000 feet of Sespe. It occurred as shallow as 100 feet or so in some wells.

In the abandoned Pirie field near Ojai, originally drilled about 1900 on seepages, the oil measures were in the lower 2,000 feet or so of the Sespe. The oil is heavy and tarry.

The Sespe oil zones in the Elwood field, according to Mason Hill[19] are: (1) 0–20 feet below the top; (2) 850 feet below the top; (3) 1,900 feet below the top or about 600 feet above the base. The production is erratic and spotty.

In the Capitan field the upper 650 feet or more of Sespe contains gas sands. The top of the highest Sespe oil sand is about 650 feet below the top and ten or more sands extending to the base of the Sespe produce 40°–43° gravity oil, as shown somewhat diagramatically in Figure 4. At least one good well was obtained recently in the top 100 feet of the Coldwater sandstone. One of the interesting features of some of the producing Sespe sand cores observed is the presence of black solid hydrocarbon films around the grains in some of the oil sands. The lighter oil occurs between these asphalt-coated grains and seems to be dissolving the solid films as shown by the darker staining in the light oil next to the films. This suggests that some of the Sespe oil sands were saturated at an earlier time and that this oil had escaped except for the black films left coating the grains. Later more oil migrated into the Sespe and resaturated the sands.

[14] T. F. Stipp, *op. cit.*

[15] Wm. C. Bailey, "Shiells Canyon Area of Bardsdale Field," *Summary of Operations, California Oil Fields*, Vol. 31, No. 1 (1945), pp. 19–26.

[16] Loring B. Snedden, "Bardsdale Area of the Bardsdale Oil Field," *California Dept. Nat. Res., Div. of Mines Bull. 118* (1943), p. 406.

[17] Loring B. Snedden, "South Mountain Oil Field," *ibid.*, pp. 404–5.

[18] Thomas Clements, "Sespe Oil Field," *ibid.*, pp. 395–99.

[19] Mason L. Hill, "Elwood Oil Field," *ibid.*, pp. 380–83.

Also the common occurrence of commercial accumulations of oil in erosionally truncated sands suggests that all the available oil does not escape from the source-rock shales during one period of folding and faulting. On the contrary, later periods of tectonic activity seem to be able to squeeze out more liquid oil as well as gas from the source rocks. This oil and gas then may accumulate in sands that were formerly exposed at the surface and partly eroded.

### SOURCE ROCKS FOR SESPE OIL

Sandstones in this region are all low in organic material except for small fragments of carbonized wood that is common in thin zones in some localities. Therefore, except for minor quantities of gas, the sandstones are all excluded as probable source sediments along with the Sespe redbeds themselves, which rarely contain any organic material except a few bones and carbonized wood fragments. Only marine shales containing recognizable organic material in abundance are considered as probable source sediments. Under the method of multiple hypothesis, suppose we consider all the marine shales that are in juxtaposition to the Sespe in and near fields producing from this formation, as possible source rocks and see which fit the evidence best. These are as follows.

1. Middle and lower Eocene (Domengine or Llajas and older)
2. Upper Eocene (Tejon)
3. Oligocene (known in the Ventura basin only at the extreme northwest end)
4. Miocene
5. Pliocene

*Middle Eocene.*—Llajas dark gray shales containing common fossils including foraminifera and considerable finely divided organic material are interbedded with the producing sands and similar dark foraminiferal shales of the Santa Susana formation (also middle Eocene) underlie them. Stipp[20] gives a total thickness of more than 6,000 feet of middle and lower Eocene shales in the Simi field. The basal part of this shale section may be lower Eocene but at least 4,500 feet of it is middle Eocene. More than half of this shale is dark-colored; the rest is bluish gray and apparently not rich in organic material. Although it is not an obvious source rock like some of the Monterey and Kreyenhagen highly bituminous shales, it is the only plausible source rock for both the marine Eocene and basal Sespe oil in the Simi Valley region. The producing part of the Sespe is of course upper Eocene here according to the vertebrate evidence. Only a few hundred feet of upward migration is required to get oil into the Sespe near Simi. As Sespe on the south side is faulted against middle Eocene along the Simi fault there is no known post-Eocene source in the Simi syncline on the south. The nearest Monterey shales are 1½ miles north (resting unconformably on the Sespe), and to get oil from them would require downward migration through 5,000 feet of lower Miocene and Sespe beds as well as more than 2,000 feet of middle Eocene to the

[20] T. F. Stipp, "Simi Oil Field," *California Dept. Nat. Res., Div. of Mines Bull. 118* (1943), pp. 417–23.

lower oil beds in the basal Llajas. This is so improbable that it is absurd, especially when there is an adequate middle Eocene source close at hand.

The Eocene underlying the Oak Ridge fields, including Shiells Canyon, Bardsdale, and South Mountain, is described by Snedden[21] as "a series of dark-gray, hard carbonaceous silts and silty shales with hard, tight, well-indurated fine- to medium-grained sands" and by Wm. C. Bailey[22] as "brittle, dark brown and black carbonaceous[23] shale, and . . . fine- to medium-grained highly cemented to friable sand." The upper few hundred feet of this marine Eocene may be upper Eocene (lower Tejon) but middle Eocene (Domengine) fossils have been reported not far below the base of the Sespe so that most of the dark shale and speckled siltstone section is middle Eocene. It contains abundant "worm tracks" like the "worm impression shale member"[24] 170–800 feet below the top of the Llajas in the Simi field, and 250 feet below the base of the Sespe in a well at Los Posas Hills (Shell's Everett No. 1) that contained a good middle Eocene fauna[25] in the cores, including abundant *Turritella buwaldana*. In order to reach its present position, mainly 2,000–4,000 feet above the base of the Sespe, considerable vertical migration is required. The lower 2,000 feet of lower Sespe through which it would need to have passed is mainly sandstone with only minor, somewhat lenticular red and green shale streaks and presents no problem in upward migration. However, most of the oil has accumulated in sands within the middle shalier part of the Sespe instead of in the top of the lower sandstone member and some of it has reached positions more than 4,000 feet above the base of the Sespe, requiring migration through at least several hundred feet of shale alternations as well as more than 3,000 feet of sand. This migration through shale is evidently accomplished by slow movements of gas bubbles and oil films along numerous tiny joints and cracks in the shale as well as around some of the more lenticular shale bodies. Such cracks lined with oil films have been observed by the writer in many cores of Sespe shales as well as other shaly beds in California oil fields. Some migration has probably followed certain minor tensional (normal) faults which have been noted in most of the Oak Ridge fields. The large compressional (reverse) faults probably have more of a sealing effect on oil accumulations rather than acting as avenues for migration; they are commonly lined with gouge, although some migration may take place along certain reverse-fault shear planes. Of course migration across reverse faults from the footwall to the hanging-wall block is readily accomplished where large sand bodies are faulted against sands and there is not enough shale to furnish a seal of gouge.

[21] Loring B. Snedden, "Bardsdale Area of the Bardsdale Oil Field," *ibid.*, p. 406.

[22] Wm. C. Bailey, "Shields Canyon Area of Bardsdale Field," *Summary of Operations, California Oil Fields*, Vol. 31, No. 1 (1945), pp. 19–26.

[23] The dark color of this shale is not necessarily due entirely to finely divided carbonaceous material; part of the dark substance may be bituminous.

[24] T. F. Stipp, *op. cit.*

[25] The upper 250 feet of marine Eocene in this well contained an upper Eocene fauna.

The middle Eocene (Sisar) black shales exposed in the Santa-Ynez-Topatopa Mountains north of the Santa Clara Valley are low in recognizable organic remains except for finely divided organic matter which gives them their dark color and which may have contributed some oil to the Sespe and Coldwater sandstones in the fields north of the Santa Clara River. At several localities in the Santa Ynez Mountains west of Gaviota Pass a well laminated, richly foraminiferal shale is found a little below the middle of the Eocene section, above the middle Eocene orbitoid limestone horizon. The organic shale is either upper Domengine or lower Tejon in age. Kelp-like algal impressions are also common in this shale. One of the best outcrops is near the head of Cuarta Canyon, $3\frac{3}{4}$ miles due west of Las Cruces, where about 500 feet of this highly organic shale are exposed. Although apparently bituminous no oil seepages have been observed in this shale or adjacent sandstones; weak oil showings have been noted in wells near Pt. Concepcion close to this organic shale zone.

Although few seepages of oil are found in middle Eocene shale outcrops, the occurrence of oil just above them and interstratified with them in the Simi field is believed to be valid evidence that these shales constitute source rocks. In core holes recently drilled by the Shell Oil Company near Chatsworth, about 10 miles southwest of the Simi field, highly organic laminated bituminous Eocene shales were cored. The oil now stored in the Sespe both at Simi (Tapo Canyon) and probably in the Oak Ridge fields also is most probably derived from these middle Eocene shales. In the Oak Ridge fields (including South Mountain) some of it may have come from upper Eocene shales as discussed in the following paragraphs.

*Upper Eocene source rocks (Tejon shales).*—The Cozy Dell shale contains a prolific Tejon fauna in several localities near Ojai which establish its age as upper Eocene. Some of the more diagnostic species are *Turritella uvasana* (typical) and var. *sargeanti*, *Pecten calkinsi*, *Ficopsis hornii*, *Pseudoperissolax blakei*, *Macrocallista conradiana*, and *Pitaria tejonensis*. The Cozy Dell shale ranges in thickness from a few hundred feet in Gaviota Canyon and westward to 3,200 feet north of Ojai and comprises an important middle member of the Tejon group in the Santa Ynez-Topatopa Mountains. Foraminifera and fish scales are present but rather uncommon except in a few localities. On the other hand plant impressions, particularly strap-like rushes and marine algae (kelp-like plants) are more common. Since diatoms are a type of one-celled alga, why can not more complex algae generate petroleum? Trask[26] found that sediments from an algal lake yielded a larger percentage of oil on distillation than any other type of recent sediment. Marine algae are very common in the oil-bearing Monterey shale outcrops west of Santa Barbara. From a sample of this shale furnished by the writer, Trask obtained one of his highest percentages of oil on distillation. Large seepages of tarry oil issue from the Cozy Dell shale in Toro and Oil Canyons northwest of Carpinteria and in Rincon Creek canyon northeast of that town. Oil seepages occur in

[26] Parker D. Trask and C. C. Wu, "Does Petroleum Form in Sediments at Time of Deposition?" *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 11 (1930), pp. 1451–63.

the Cozy Dell shale and overlying Coldwater sandstone near the San Cayetano thrust (Silverthread oil field) between upper Santa Paula and upper Sisar Canyons north of Santa Paula but this oil could have migrated from Miocene organic shales below the thrust. The oil seepage from the lower Tejon (white arkosic) sandstone of the Topatopa member of the Tejon (Fig. 3) in Echo Falls Canyon 2 miles north of the outcrop of the San Cayetano thrust may have seeped upward from the Miocene below the thrust, but, if so, it would need to have migrated upward through the thrust zone and a vertical distance of 4,000–5,000 feet or more above the thrust to reach the outcrops of lower Tejon from which it now seeps. As the Eocene section is overturned here it could have been derived by a shorter vertical and lateral migration from the Cozy Dell shale. Also oil seepages from the Cozy Dell shale (and Coldwater and Sespe sandstones above) in Sespe Canyon 8 or 9 miles north of Fillmore are probably too far north of the San Cayetano thrust for oil to have migrated from any Miocene below the thrust here because it is improbable that Miocene exists below the thrust that far north. The Cozy Dell shale is the most easily available source rock here.

The foregoing evidence suggests that, in spite of the comparative scarcity of recognizable organic remains in it, the upper Eocene Cozy Dell shale is the most easily available of possible source rocks and, therefore, the most probable source rock for the oil now stored in the Sespe and underlying Coldwater sandstone north of the Santa Clara River and westward to Pt. Concepcion. This includes the Sespe Canyon oil fields, the abandoned Pirie oil field south of Ojai, the Sespe oil in the Elwood field and possibly Vaqueros oil as well, the Tecolote field (north of Elwood) and the Capitan field, farther west, as well as the showings found in the Sespe as far west as Santa Anita Station, near Pt. Concepcion. Numerous other wells in the Santa Barbara region have cored oil sands of non-commercial quality in the Sespe, pointing to a widespread source sediment and not freak conditions due to faulting in certain localities.[27] The Capitan and Tecolote fields especially offer no reasonable possibility for their oil to have been derived from the Miocene because no faults in the vicinity are large enough to have brought Miocene organic shales against middle and lower Sespe which contains most of the oil sands. The Tecolote field is located too far from the Santa Barbara channel, under which concealed thrusts may be located, for oil to have migrated upward from Miocene below a great thrust and there is no evidence that thrusts of sufficient magnitude exist in this vicinity. Therefore, the Eocene shales seem to be the only logical source for this lower Sespe oil. Several near-vertical longitudinal faults of moderate throw lie between the Tecolote field and the coast line and these would tend to block inland migration of oil originating beneath the Santa

[27] Since this paper was presented, an apparently commercial gas field has been discovered in a wildcat well located by the writer. The discovery well, Rothschild Oil Company's Orella No. 1, is 2,000 feet northwest of the mouth of Refugio Canyon, 1 mile west of the Capitan field in Santa Barbara County. This field is called the Refugio Canyon field. It is on a faulted anticline similar to Capitan.

Barbara channel at the south. These faults are not large enough to bring Sespe against Monterey source rocks.

As shown in Figure 3 it is possible that at least part of the Sespe oil in the South Mountain and Oak Ridge fields of Ventura County was derived from upper Eocene shales into which the lower Sespe might change northward, provided marine upper Eocene shales are still present beneath the Santa Clara Valley syncline so that any oil derived from them could migrate laterally southward into the lower Sespe (upper Eocene) non-marine equivalent. It would still have to migrate upward from lower Sespe into the middle Sespe where it is now stored. If this lateral migration occurred it probably took place before great movements on the Oak Ridge thrust had occurred, because the upper Eocene on the downthrown (north side) of the Oak Ridge fault is brought against middle Eocene or older beds on the upthrown side at present.

An Eocene source for the oil now stored in the Sespe was suggested as early as 1913 by Dorsey Hager.[28] Kew[29] in 1924 stated that the Sespe oil in Oak Ridge-South Mountain fields "probably has the same origin as that in Simi Valley, where it is evidently derived from organic shales in the Martinez and Meganos formations (lower and middle Eocene). From these shales it has migrated through fissures into sands of the Sespe."

Taliaferro, Hudson, and Craddock[30] in 1924 stated "It is generally assumed that the oil obtained in the Sespe formation in Ventura County has its origin in Eocene shales. This assumption has considerable support but there are other possible sources for the oil."

However, many geologists in California have contended that the Eocene shales are not rich enough in organic material to constitute a source rock and believe that the Sespe oil in Ventura County has come from the Miocene and Pliocene shales beneath the Oak Ridge fault and San Cayetano thrust. As discussed more fully in the following paragraphs this would not explain the Sespe oil in the Santa Barbara County fields where no such thrusts are known.

*Oligocene source rocks.*—Only at the extreme west end of the Ventura basin, near Lompoc and Pt. Concepcion is there any appreciable amount of marine shale in the Oligocene. Most of this shale is silty and low in organisms but a few thin beds of laminated organic shale are noted south of Lompoc. Of course there is some possibility that the Sespe some miles off-shore from Santa Barbara and therefore unknown, may change southward as well as westward into marine sandstones and finally into marine shales of the source rock type. So far as known, only Oligocene? redbeds have been reported on the Channel Islands, 20–40 miles

[28] Written communication, November 10, 1946.

[29] W. S. W. Kew, "Geology and Oil Resources of a Part of Los Angeles and Ventura Counties, California," *U. S. Geol. Survey Bull. 753* (1924), pp. 27–28; 162.

[30] Taliaferro, Hudson, and Craddock, "The Oil Fields of Ventura County, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8, No. 6 (1924), p. 796.

offshore from the Santa Barbara coast line. On the other hand redbeds of probable upper Sespe (lower Miocene) age are well developed in Topanga Canyon and farther southeast near Santa Monica in the Santa Monica Mountains. As the Channel Islands are the westward continuation of the Santa Monica Mountains and the two together form the south rim of the Ventura basin, the known evidence is against such a southward change of the Sespe into marine beds. In the Lompoc-Pt. Concepcion area marine Oligocene sandstones become more shaly suggesting deeper water toward the north, as though a marine embayment was developed between Pt. Concepcion and Lompoc in Oligocene time. This sketchy evidence does not suggest any southward change of the Oligocene into marine beds but, on the contrary, a westward or even northwestward change. Of course we know there was an extensive marine Oligocene sea continuing over from the upper Eocene in the San Joaquin Valley and that thousands of feet of oil-rich Kreyenhagen shales were deposited in it. The Kreyenhagen known nearest to the Ventura basin is some 60 miles north of the west end of the Ventura basin and is in an entirely different basin.[31] From the foregoing evidence it seems improbable that marine Oligocene is the source of Sespe oil. Even if marine Oligocene source rocks do exist beneath the western part of the Santa Barbara channel they could not logically be the source of Sespe oil in such interior domes as Shiells Canyon, Torrey Canyon, Sespe Canyon, Simi, and Tecolote. If the Eocene is the source in these Sespe fields, why could it not constitute adequate source rocks in all Sespe fields?

*Miocene and Pliocene as source rocks for Sespe oil.*—Only in the South Mountain-Oak Ridge and Sespe Canyon fields where the upper Pliocene and Pleistocene are faulted against the Sespe along the Oak-Ridge and San Cayetano faults is there any possibility of the Miocene or Pliocene shales being source rocks for Sespe oil. As young Pliocene or Pleistocene rests against Sespe in these oil fields, as shown by several wells that passed from lower Sespe into Pleistocene sands and gravels, any oil originating in the Monterey, Santa Margarita, or lower Pliocene shales would have to pass through a considerable thickness of Eocene shales which are now faulted against lower Pliocene-Miocene in order to reach the Sespe above. If the oil is assumed to come up the fault, why are most of the Pliocene-Pleistocene sands underlying and north of the Sespe along the Oak Ridge fault so barren? It hardly seems plausible that practically all the oil migrating along a fault plane should pass through thousands of feet of shale and gouge (in Figure 3 middle Eocene is faulted against lower Pliocene-upper Miocene shales) and collect only in the hanging-wall block instead of part of it collecting in highly porous and pervious sands along the footwall side of the 55°-dipping reverse fault.

Of course at some time in the development of the Oak Ridge fault (probably in middle Pleistocene) the Miocene oil shales on the downthrown side were in

[31] Ralph D. Reed, *Geology of California*, Amer. Assoc. Petrol. Geol. (Tulsa, 1933), pp. 147–62.

contact with the middle Sespe. Oil from this Miocene or from the Pliocene above could have moved across the fault into the Sespe, provided it could get through the shaly gouge along the fault. This possibility can not be definitely ruled out although it does not appeal to the writer as the most plausible explanation. There is no reasonable likelihood of getting oil into the Sespe from the Pliocene-Miocene in such fields as Tecolote or Capitan, where no such thrusts are present, as shown by deep wells in both fields.

## CONCLUSIONS

The oil now being produced from the Sespe in the Ventura basin apparently had its source mainly in Eocene shales.

1. In the Simi Valley district this oil originated in middle and lower Eocene shales.

2. In the South Mountain-Oak Ridge group of fields the oil either originated in the middle Eocene shales below or part of it came from upper Eocene shales, into which the lower Sespe possibly changes northward, and migrated laterally southward from the Santa Clara syncline into the lower Sespe and thence vertically into the middle Sespe. It is possible that some of it migrated from Miocene or Pliocene across the Oak Ridge fault.

3. In the fields north of the Santa Clara River, from Sespe Creek to Capitan inclusive, the oil must have come mainly from upper Eocene shales and migrated upward through the Coldwater sandstone into the Sespe.

Countless tiny cracks and joints in the shale interbeds between the source rocks and the middle or upper Sespe in which part of the oil has accumulated are advanced as the most logical channels of upward migration. In the writer's opinion completely impervious seals or cap rocks rarely if ever exist through long epochs of geologic time and at least minute quantities of oil or gas are continually escaping from all major oil accumulations.

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# PENNSYLVANIAN STRATIGRAPHY OF COLORADO SPRINGS QUADRANGLE, COLORADO[1]

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## ABSTRACT

Detailed study of two Pennsylvanian formations, the Glen Eyrie and the Fountain, within a limited area along the east flank of the Colorado Front Range indicates that such investigation is fundamental to a more thorough understanding of redbed stratigraphy.

The Glen Eyrie and Fountain formations in the vicinity of the Manitou embayment were deposited in a deltaic environment during mid-Pennsylvanian time. Sediments were derived from a highland whose eastern margin closely coincided with that of the present Front Range. Climatic conditions over both the highland and the delta surface were more humid than at present.

The Glen Eyrie contains a varied fauna consisting principally of ostracods and conodonts. These, in conjunction with brachiopods from a lower Fountain limestone, indicate that the two formations are of Marmaton or later age as recognized in the Mid-Continent Pennsylvanian section.

Detailed descriptions of the type sections of the Glen Eyrie and Fountain formations are presented for the first time. Maps showing the distribution of the two formations within the Colorado Springs Quadrangle and the extent of thin limestone beds within the Fountain of the southwestern quarter of the quadrangle are included. The Glen Eyrie has been raised from its former status as a member of the Fountain to the rank of formation.

Subsurface data from four wells reveal that, for a distance of 18 miles at least, the Fountain thickens eastward at a rate of approximately 100 feet per mile. Well samples indicate no marked lithologic change in the Fountain through this distance. The Glen Eyrie is represented in the two easternmost of these wells by a thin section of shales and limestones at the base of the Fountain.

## INTRODUCTION

Correlation among the various redbed formations of the Rocky Mountain province and the relationships of the redbeds as a whole to Upper Paleozoic and Mesozoic sections outside the province have long been major stratigraphic problems. Within recent years mounting interest in the oil potentialities of the Rocky Mountains has increased the necessity for solution of at least parts of these problems. Broad reconnaissance studies and correlations based on them will not supply the information needed to work out the details of Rocky Mountain stratigraphy and structure.

Detailed study of the Glen Eyrie and Fountain formations has revealed new evidence about their age and environment of origin. This evidence is presented as a contribution toward the ultimate solution of the redbed problems. It is hoped that the results of this work will stimulate additional detailed studies in other key

[1] A contribution from the Louisiana State University Field Camp, submitted as a dissertation in partial fulfillment of the requirements for the degree of Doctor of Philosophy at Louisiana State University, May, 1947. Manuscript received, May 15, 1947.

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areas, such as the Canon City embayment and the Arkansas Valley above the Royal Gorge, which will both verify the conclusions drawn in this paper and contribute further to knowledge of Rocky Mountain stratigraphy.

The present study is limited essentially to the Colorado Springs Quadrangle within which there are two main areas of Pennsylvanian exposures (index map, Fig. 1). One of these areas, the Manitou embayment, includes the type locality and only known exposures of the Glen Eyrie formation and the type locality and thickest known section of the Fountain formation. Both of these formations are Pennsylvanian in age. The second area, in the southwest quarter of the quadrangle, includes Fountain only and extends from the valley of Little Fountain Creek southwestward almost to the mouth of Beaver Creek Canyon.

In the Manitou embayment (map, Fig. 2) the Glen Eyrie and Fountain formations were mapped in detail. A section including both formations was measured and described along the valley of Fountain Creek between Manitou and Colorado Springs, the type locality of the Fountain. Two sections of the Glen Eyrie formation were measured and described near the head of Black Canyon in the northern part of the embayment. In the southwestern part of the quadrangle (map, Fig. 3), the area of Fountain exposures and the extent of certain limestone beds within the formation were mapped. A section of Fountain extending along the valley of Little Fountain Creek was measured and described, and sections along Turkey Creek and across Sand Creek were measured.

Field work was done during the summers of 1941, 1942, and 1946. In addition to detailed study in the Colorado Springs Quadrangle the writer spent approximately one week in reconnaissance of Garden Park at the north end of the Canon City embayment, and in observation of some of the exposures of Fountain and overlying formations between Denver and the Colorado-Wyoming state line.

## PREVIOUS WORK

The Fountain formation was named by Cross[3] as a series of red arkosic sandstones and conglomerates well exposed on Fountain Creek below Manitou Springs in the Colorado Springs Quadrangle. He assigned the Fountain to the Carboniferous because of lithologic similarity to redbeds on the Arkansas River 50 miles west, from which Carboniferous fossils had been described. The maximum thickness measured within the Pikes Peak Quadrangle was 1,000 feet. No detailed description was given and no mention made of the possible environment in which these red sediments were deposited.

Prior to Cross's work the redbeds along the Front Range had been assigned to the Triassic by Hayden,[4] who noted a maximum thickness of 2,000 feet within the Colorado Springs Quadrangle but made no detailed description. "Very coarse

[3] C. W. Cross, "Description of the Pikes Peak Quadrangle, Colorado," *U. S. Geol. Survey Geol. Folio 7* (1894).

[4] F. V. Hayden, *Annual Report of the U. S. Geol. and Geographical Survey of Territories, Embracing Colorado and Parts of Adjacent Territories, 1874* (1876), pp. 42–46.

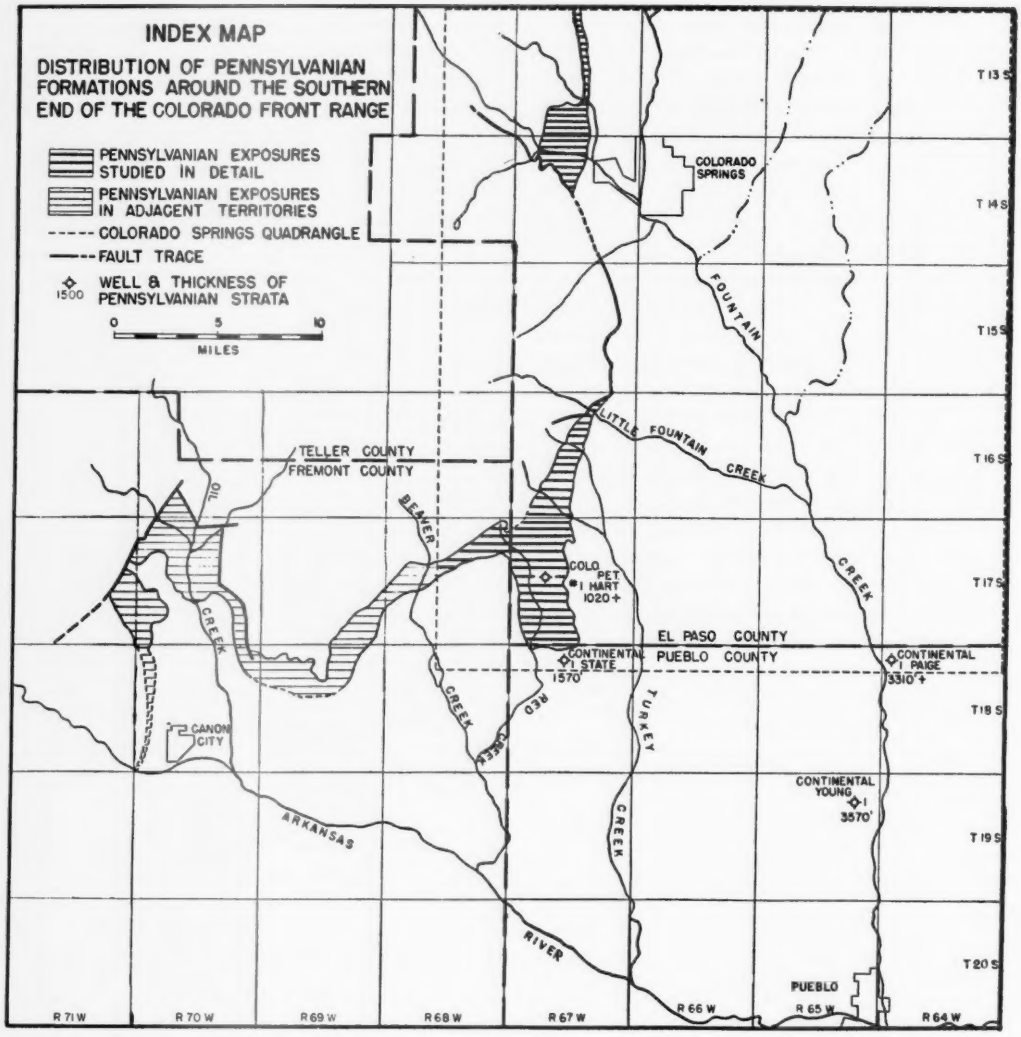
INDEX MAP
DISTRIBUTION OF PENNSYLVANIAN FORMATIONS AROUND THE SOUTHERN END OF THE COLORADO FRONT RANGE
PENNSYLVANIAN EXPOSURES STUDIED IN DETAIL
PENNSYLVANIAN EXPOSURES IN ADJACENT TERRITORIES
COLORADO SPRINGS QUADRANGLE
FAULT TRACE
1500 WELL & THICKNESS OF PENNSYLVANIAN STRATA
0 5 10
MILES
COLORADO SPRINGS
FOUNTAIN
LITTLE FOUNTAIN CREEK
TELLER COUNTY
FREMONT COUNTY
OIL
BEAVER
CREEK
COLO PET
1 HART
1020+
EL PASO COUNTY
PUEBLO COUNTY
CONTINENTAL
1 STATE
1570'
CONTINENTAL
1 PAIGE
3310'+
CANON CITY
RED CREEK
TURKEY CREEK
CONTINENTAL
YOUNG
1
3570'
ARKANSAS RIVER
PUEBLO
T 13 S
T 14 S
T 15 S
T 16 S
T 17 S
T 18 S
T 19 S
T 20 S
R 71 W
R 70 W
R 69 W
R 68 W
R 67 W
R 66 W
R 65 W
R 64 W

FIG. 1

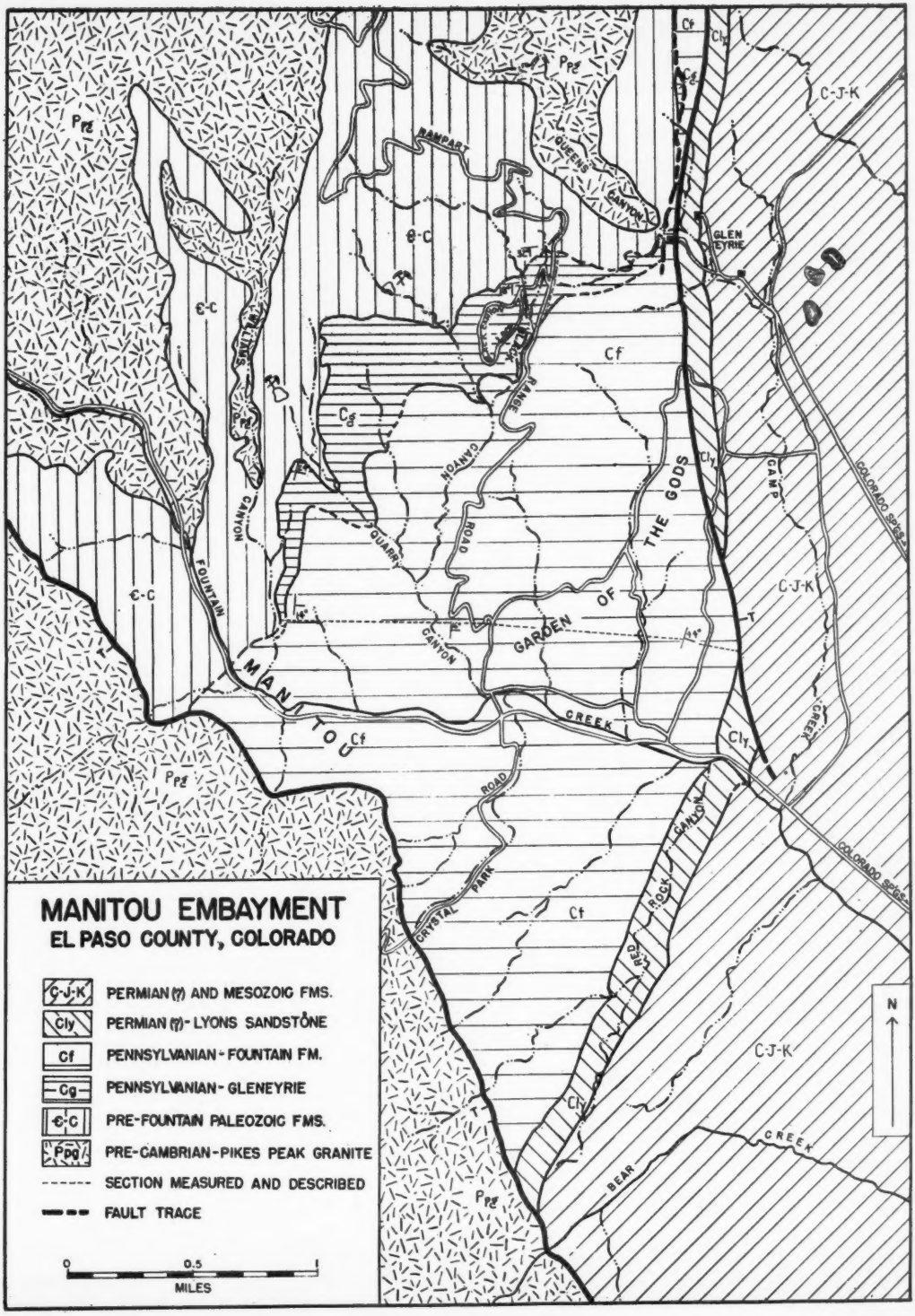
MANITOU EMBAYMENT
EL PASO COUNTY, COLORADO
C-J-K PERMIAN (?) AND MESOZOIC FMS.
Cly PERMIAN (?) - LYONS SANDSTONE
Cf PENNSYLVANIAN - FOUNTAIN FM.
Cg PENNSYLVANIAN - GLENEYRIE
€-C PRE-FOUNTAIN PALEOZOIC FMS.
Ppg PRE-CAMBRIAN - PIKES PEAK GRANITE
SECTION MEASURED AND DESCRIBED
FAULT TRACE
0 0.5 1
MILES
N
MANITOU
GARDEN OF THE GODS
GLEN EYRIE
CAMP
COLORADO SPGS.
RAMPART
QUEENS CANYON
RANGE
SQUARE
ROAD
CANYON
FOUNTAIN
CREEK
CRYSTAL PARK
ROCK
BEAR

FIG. 2

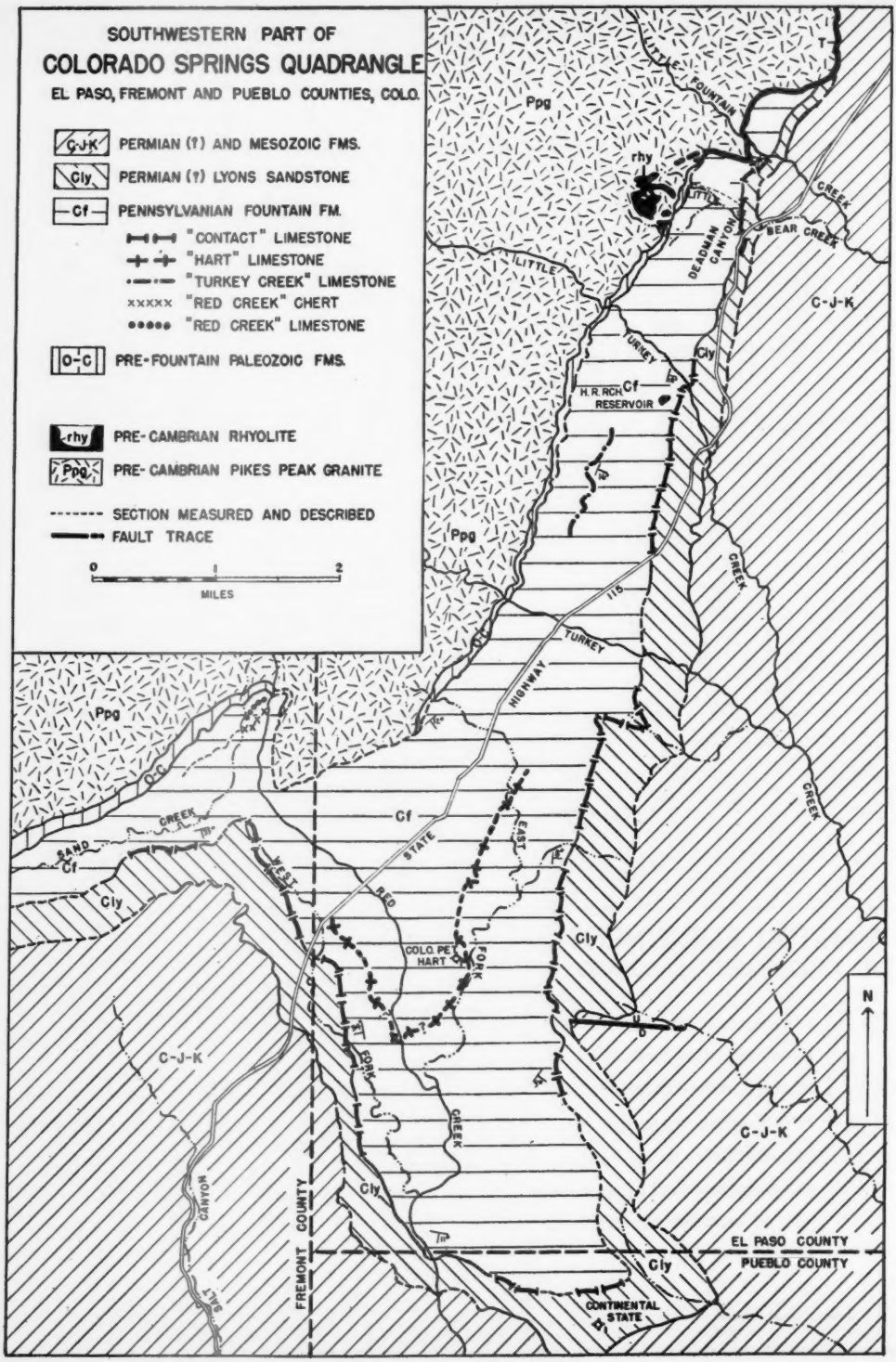
SOUTHWESTERN PART OF
COLORADO SPRINGS QUADRANGLE
EL PASO, FREMONT AND PUEBLO COUNTIES, COLO.
PERMIAN (?) AND MESOZOIC FMS.
PERMIAN (?) LYONS SANDSTONE
PENNSYLVANIAN FOUNTAIN FM.
"CONTACT" LIMESTONE
"HART" LIMESTONE
"TURKEY CREEK" LIMESTONE
"RED CREEK" CHERT
"RED CREEK" LIMESTONE
PRE-FOUNTAIN PALEOZOIC FMS.
PRE-CAMBRIAN RHYOLITE
PRE-CAMBRIAN PIKES PEAK GRANITE
SECTION MEASURED AND DESCRIBED
FAULT TRACE
0
1
2
MILES
Ppg
rhy
Cly
Cf
C-J-K
H.R. RCH RESERVOIR
TURKEY CREEK
HIGHWAY 115
STATE
WEST
EAST
RED
COLO. PET HART
FORK
SAND
CANYON
SALT
FREMONT COUNTY
EL PASO COUNTY
PUEBLO COUNTY
CONTINENTAL STATE
LITTLE
FOUNTAIN
DEADMAN CANYON
BEAR CREEK
N

FIG. 3

conglomerates becoming finer eastward" were found south of Manitou Springs (in the Manitou embayment) and were interpreted as having been "laid down along the base of the Front Range as a shore line," suggesting that Hayden considered these redbeds to be part marine.

Finlay,[5] in 1907, named and described the Glen Eyrie formation as 40 feet of quartz sands and black carbonaceous shales occurring immediately below the Fountain in the Manitou embayment. The shales contain fossil plants which were identified by David White as being Pottsville in age. Finlay also reported the finding of brachiopods 200 feet above the base of the Fountain but does not give further details. The publication does not include a measured section or detailed description of the Glen Eyrie.

Glen Eyrie deposition was interpreted as having taken place in swampy areas near sea-level. The basal contact of the Glen Eyrie was described as an erosional unconformity, the Glen Eyrie-Fountain contact as an "unconformity with overlap."

Finlay,[6] in 1916, presented a very generalized description of the Fountain in the Manitou embayment where a maximum thickness of 4,500 feet, with no duplication of section by faulting, was measured. The lowermost 90 feet was discussed and mapped separately as the Glen Eyrie shale member of the Fountain. Fountain deposition was interpreted as starting under low, coastal, swampy conditions (Glen Eyrie), followed by widespread terrestrial deposition of materials washed down from an arid upland. A change to marine conditions was postulated for the upper Fountain because of marine faunas found in limestones of northern Colorado that were correlated as upper Fountain equivalents.

Tieje,[7] describing the Fountain in the Colorado Springs area, noted greenish and gray sandstones, and cross bedding which dipped eastward more gently than did the formation. The Fountain was dated as Pennsylvanian, partly on the basis of a *Lingulodiscina* (Lower Carboniferous brachiopod) found in a pocket of green shale 475 feet from the base of a 2,000-foot section of the formation near Colorado Springs.

The Fountain, in Tieje's opinion, was deposited by streams wandering over a piedmont plain extending eastward from a Paleozoic Front Range during a time of semi-aridity.

## GENERAL GEOLOGY OF QUADRANGLE

The Colorado Springs Quadrangle includes parts of the Rocky Mountain Front Range, the Great Plains, and the foothills between the two. Thus the rocks

[5] G. I. Finlay, "The Gleneyrie Formation and Its Bearing on the Age of the Fountain Formation in the Manitou Region, Colorado," *Jour. Geol.*, Vol. 15 (1907), pp. 586–89.

Note: In all literature subsequent to Finlay's 1907 paper the formation name, as well as that of the stream and estate from which the formation was named, has appeared as "Glen Eyrie." To avoid confusion the writer has followed this generally accepted spelling.

[6] G. I. Finlay, "Description of the Colorado Springs Quadrangle, Colorado," *U. S. Geol. Survey Geol. Folio 203* (1916).

[7] A. J. Tieje, "The Red Beds of the Front Range in Colorado: A Study in Sedimentation," *Jour. Geol.*, Vol. 31 (1923), pp. 192–207.

exposed are those of the pre-Cambrian complex of the mountain province and the Paleozoic and younger sediments which dip generally eastward off the complex. Pre-Cambrian rocks are exposed over most of the western third of the quadrangle. Outcrops of Paleozoic formations that in general dip steeply eastward form a discontinuous irregular foothill belt along the eastern and southern flanks of the mountains. Mesozoic and Tertiary formations, most of which dip gently eastward, underlie nearly all the eastern two-thirds of the quadrangle which is a part of the Great Plains. Gravels of Quaternary age cover tilted and truncated Paleozoic and Mesozoic formations over large areas along the mountain front.

Table I shows the stratigraphic relationships of the Glen Eyrie and Fountain to the older formations within the Colorado Springs Quadrangle.

TABLE I

PRE-MESOZOIC ROCKS OF COLORADO SPRINGS QUADRANGLE

| *Era* | *Period* | *Formation* |
|---|---|---|
| | *Unconformity* | |
| | Permian? | Lykins formation |
| | Permian? | Lyons sandstone |
| | Pennsylvanian | Fountain formation |
| | Pennsylvanian | Glen Eyrie formation |
| | *Unconformity* | |
| | Mississippian | Madison limestone* |
| | *Unconformity* | |
| Paleozoic | Devonian | Williams Canyon formation |
| | *Unconformity* | |
| | Ordovician | Harding sandstone* |
| | *Unconformity* | |
| | Ordovician | Manitou dolomite* |
| | *Unconformity* | |
| | Cambrian | Sawatch formation |
| | *Unconformity* | |
| | ? | Rhyolite intrusives* |
| | ? | Pikes Peak granite* and older crystalline rocks. |

* Formations on which Pennsylvanian strata are known to rest unconformably at one or more places w ithin the quadrangle.

## GLEN EYRIE FORMATION

The Glen Eyrie formation consists of a series of shales and sandstones which rests unconformably on the Madison limestone and is overlain conformably and gradationally by the Fountain formation. The Glen Eyrie was named by Finlay[8] in 1907 at which time he described it as being 40 feet thick. In 1916 Finlay[9] changed the status of the Glen Eyrie to that of a member of the Fountain formation and set the thickness at 90 feet. No reason was given for these changes.

[8] G. I. Finlay, "The Gleneyrie Formation and Its Bearing on the Age of the Fountain Formation in the Manitou Region, Colorado," *Jour. Geol.*, Vol. 15 (1907), pp. 586–89.

[9] G. I. Finlay, "Description of the Colorado Springs Quadrangle, Colorado," *U. S. Geol. Survey Geol. Folio 203* (1916).

Finlay apparently named the Glen Eyrie from exposures of black shale and sandstone in fault contact with upper Fountain north of the mouth of Queens Canyon which at that time was called Glen Eyrie Creek.

*Present status.*—The writer considers the Glen Eyrie to be a separate formation despite its limited extent and its gradational relationship to the Fountain. The following considerations support this conclusion and indicate that the Glen Eyrie may be readily distinguished from the overlying Fountain.

1. The Glen Eyrie consists mainly of shale with thin beds of fine- to medium-grained non-arkosic sandstones whereas coarse arkosic sandstones and conglomerates greatly predominate in the Fountain.

2. The sandstones of the Glen Eyrie are even-bedded and do not show the cross bedding, filled channels, and other such sedimentary structures characteristic of the Fountain.

3. Fossil invertebrates at various horizons in the Glen Eyrie indicate that it is marine, at least in part, whereas the overlying Fountain is, in the Manitou embayment, non-fossiliferous. The brachiopods reported by Finlay[10] as occurring 200 feet above the base of the Fountain are believed to be from the fossiliferous dolomitic sandstone near the top of the Glen Eyrie (unit 21, Section I).

4. The Glen Eyrie is a mappable unit in the Manitou embayment.

*Occurrence.*—The most completely developed and best exposed section of the Glen Eyrie, approximately 360 feet thick, is in and near Black Canyon at the north edge of the embayment and approximately ¾ mile southwest of Finlay's probable type locality. Most of the exposures of this section are in cuts along the Rampart Range road and the Black Canyon loop, both constructed in recent years.

The total extent of the Glen Eyrie along the strike cannot be determined. It is overlapped by Fountain beds just south of the mouth of Williams Canyon within the town of Manitou (Fig. 2). Finlay states that the northernmost exposures are a short distance north of Queens Canyon and that beyond them Fountain rests on granite. However the lowest Fountain exposed is in fault contact with underlying rocks for at least several miles north of Queens Canyon. Therefore the northward extent of Glen Eyrie deposition is as indeterminate as that on the south. The formation is not known to crop out anywhere outside the Manitou embayment. The possible subsurface development of the Glen Eyrie at the east is discussed under Subsurface Development.

*Black Canyon section.*—Varicolored sandy shales constitute approximately 80 per cent of the total thickness of Glen Eyrie in Black Canyon. Black shales, most of which are gray on weathered surfaces, alternate with yellow, green, brown, and purple shales; red shales are absent. The maximum observed thickness of shale unbroken by sandstone beds or stringers was 35 feet. Fossils of marine invertebrates occur in yellow and gray shales near the base and near the middle of

[10] G. I. Finlay, "The Gleneyrie Formation and Its Bearing on the Age of the Fountain Formation in the Manitou Region, Colorado," *Jour. Geol.*, Vol. 15 (1907), p. 587.

## SECTION I

COMPOSITE SECTION OF GLEN EYRIE FORMATION AS EXPOSED IN AND NEAR BLACK CANYON, SEC. 28, T. 13 S., R. 67 W., EL PASO COUNTY, COLORADO

Over-all thickness determined by plane-table traverse; thicknesses of individual units measured by Jacob-staff traverse at time formation was described

| Description | Thickness in Feet: Of Unit | Thickness in Feet: To Bottom of Formation |
|---|---|---|
| FOUNTAIN FORMATION | | |
| Sandstone, red, thick-bedded, poorly consolidated, medium- and coarse-grained, arkosic, alternating with red arkosic and sandy shale | | |
| GLEN EYRIE FORMATION | | |
| 23. Sandstone, white with minute black specks, massive, fine-grained; stained red on surface by wash from above | 4.0 | 362.0 |
| 22. Shale, alternating gray and purple beds | 12.0 | 358.0 |
| 21. Sandstone, mottled purple and light gray, upper 3 feet massive, lower 2 feet thin-bedded, fine-grained, irregularly dolomitic, contains a few brachiopods | 5.0 | 346.0 |
| 20. Shale, alternating light gray and maroon beds | 15.0 | 341.0 |
| 19. Sandstone, light gray to white, hard, fine-grained; 2 massive beds separated by 4 inches of thin-bedded shaly sand | 2.0 | 326.0 |
| 18. Poorly exposed (a few exposures of shale) | 25.0 | 324.0 |
| 17. Sandstone, yellow and purple, irregularly bedded, hard, slightly quartzitic, partly arkosic, slightly shaly in lower part | 13.0 | 299.0 |
| 16. Shale, varicolored, with few thin beds of white and yellow hard medium-grained sandstone, poorly exposed at top | 75.0 | 286.0 |
| 15. Sandstone, mottled white and purple, hard, fine-grained, interbedded with sandy shale | 3.0 | 211.0 |
| 14. Sandstone, mottled white and purple, hard, fine-grained, thick-bedded | 8.0 | 208.0 |
| 13. Shale, varicolored, with a few thin beds of yellow hard fine-grained sandstone | 32.0 | 200.0 |
| 12. Shale, yellow and gray, silty, calcareous, fossiliferous (ostracods and brachiopods) | 5.0 | 168.0 |
| 11. Limestone, gray-brown, massive, slightly nodular, dense | 2.0 | 163.0 |
| 10. Limestone, gray-brown, nodular, interbedded with sandy and fissile shale | 2.0 | 161.0 |
| 9. Limestone, brown, coarsely crystalline to dense, sandy at top | 1.0 | 159.0 |
| 8. Shale, purple to gray, fissile | 1.0 | 158.0 |
| 7. Limestone, yellow, slightly arkosic, slightly conglomeratic, fossiliferous (poorly preserved brachiopods) | 2.0 | 157.0 |
| 6. Shale, gray and yellow, silty, micaceous, with stringers of yellow fine-grained sandstone, poorly exposed | 42.0 | 155.0 |
| 5. Sandstone, yellow with irregular purple bands, fine-grained | 2.0 | 113.0 |
| 4. Chert, dark gray to black, iron stained, finely granular to dense, jointed | 1.0 | 111.0 |
| 3. Shale, varicolored, with a few thin beds of yellow irregularly banded fine-grained sandstone | 72.0 | 110.0 |
| 2. Shale, gray, purple and brown, basal 10 feet fossiliferous (ostracods, conodonts, brachiopods, bryozoans, echinoderms) | 35.0 | 38.0 |
| 1. Sandstone, yellow to purple, irregularly cemented, fine-grained, silty | 3.0 | 3.0 |
| MADISON LIMESTONE | | |
| Limestone, gray and red, dense, dolomitic, in angular unconformity with overlying Glen Eyrie | | |

the section. Lithologically identical beds in other parts of the formation appear to be non-fossiliferous.

Sandstones constitute approximately 15 per cent of the Glen Eyrie exposures in Black Canyon. In the lower half of the formation most of these sandstones are non-calcareous, ferruginous, medium- to coarse-grained and composed largely of quartz. They are commonly thin, occurring interbedded with the shales that

make up the bulk of the section. Most are yellow or brown in color, a few are purple and a very few are red. Iron is present as interstitial cement supplemented by enough silica in some beds to make them quartzitic. The chief exception to the ordinary thinness of lower Glen Eyrie sandstones is the basal sand which varies from 4 to 13 feet in thickness over a distance of not more than ¼ mile.

In contrast the sandstones of the upper Glen Eyrie in Black Canyon are generally light-colored, fine- to medium-grained, and average 6 feet in thickness. A light gray hard dolomitic sandstone containing phosphatic shells of linguloid-like brachiopods occurs 20 feet below the top of the formation. Distribution of dolomite within the sandstone is irregular; in part the appearance is that of interbedded sandstone and dolomite, but at other places on the same outcrop the boundary between dolomitic sandstone and sandy dolomite cuts across bedding. On exposed surfaces the more dolomitic parts stand out in relief of several millimeters.

The sandstone which was mapped as the top of the Glen Eyrie in the Black Canyon area, and for some distance southwestward, is a persistent white fine-grained massive ledge-forming bed 4 feet thick. Its surface is stained red by wash from the overlying Fountain redbeds. Under it, and separating it from the dolomitic sandstone previously described, is a 12-foot section of gray and purple shales.

In an exposure 180 feet above the base of the Glen Eyrie, along the lower road of the Black Canyon loop, is an outcrop of sandy, slightly arkosic limestone containing crushed and partly dissolved brachiopod shells. The bed is 2 feet thick and occurs at the top of a section of thick shales and interbedded sandstones.

In thin section this limestone is seen to be coarsely but unevenly crystalline, with calcite constituting approximately 60 per cent of the total. Most of the remainder of the specimen is made up of angular fragments of microcline perthite and subangular to rounded fragments of quartz and quartzite, a few fragments of each being as large as 8 millimeters in diameter.

Above this slightly arkosic limestone and separated from it by 1 foot of fissile shale is a 5½-foot section of limestone beds, dense and slightly nodular at the top, nodular and impure in the middle, and more coarsely crystalline at the base. These were the only limestone beds observed in surface exposures of Glen Eyrie, in the Black Canyon section or elsewhere. In their nodular development these limestones resemble many found in the Fountain south of the Manitou embayment.

*Lateral changes.*—Southwestward from Black Canyon the Glen Eyrie thins to 122 feet at the mouth of Williams Canyon, the southernmost exposures in which a complete section may be observed. Thinning is largely at the expense of shales, as sandstones and conglomeratic sandstones comprise 50 per cent or more of the Williams Canyon section. The sandstones are more coarse-grained, more arkosic and conglomeratic, and in general more Fountain-like than in the Black Canyon area. Because of poor exposures between the two areas the exact nature of the

change from a predominantly shale section to one in which coarse clastics are dominant is difficult to determine for the formation as a whole.

The top of the Glen Eyrie throughout the area of exposure was mapped on the horizon above which there are no shales of appreciable thickness. In the northern part of the area, from Black Canyon to near Quarry Canyon (Fig. 2), this horizon is the top of the ledge-forming white sandstone previously described (unit 23, Section I). From Quarry Canyon southward the horizon used was the top of a coarse- to medium-grained bright yellow sandstone about 6 feet thick (unit 9, Section II) conformably overlain by massive arkosic conglomeratic sandstones and underlain by several feet of gray and yellow non-fossiliferous shale.

Within the Glen Eyrie interfingering of sandstones from the south with shales from the north makes through tracing of many individual beds almost impossible. The basal beds, however, are well enough exposed that a clear picture of the lateral changes they undergo may be obtained. In Black Canyon the basal unit is a firm irregularly cemented yellow to brown medium-grained sandstone averaging 5 feet in thickness and occurring in beds 1–1½ feet thick. On the south and west, basal beds, wherever exposed, are similar but ordinarily more quartzitic. Some are slightly conglomeratic with poorly rounded quartz pebbles up to ½ inch in diameter. On the north rim of Quarry Canyon these basal sands are much more ferruginous, bright red, and rather friable. There are thin layers of purple hematitic siltstone, which become more numerous southward. Near the mouth of Williams Canyon the basal sands include beds up to 6 inches thick of slightly siliceous hematite.

*Glen Eyrie-Madison contact.*—The unconformity between the basal Glen Eyrie sandstones and the Madison limestone is exhibited by the difference in attitude between the two formations. Near the head of Black Canyon the Madison strikes N. 80° E. and dips 32° S. The overlying Glen Eyrie sandstone strikes N. 75° E. but dips only 18° S. At the mouth of Williams Canyon the strike of the basal Glen Eyrie beds is N. 8° E. and the dip is 14° E. The attitude of the underlying Madison is difficult to determine, but truncation of weathered limestone conglomerate by the overlying sandstones may be seen in road cuts east of the mouth of the Canyon.

*Paleontologic summary.*—Fossils were found in the following four units within the Glen Eyrie.

1. A shale (unit 2, Section I) 15–20 feet above the base of the formation on the Rampart Range road. The fauna consists of ostracods and conodonts with a few poorly preserved productid type brachiopods and fragments of bryozoans, corals, and echinoderms.

2. A sandy limestone (unit 7, Section I) 157 feet above the base of the formation on the lower road of the Black Canyon loop. A few crushed brachiopods were found.

3. A shale (unit 12, Section I) 168 feet above the base of the formation in the same exposure as that of 2. The fauna consists of ostracods and brachiopods very

similar to those of unit 2 of the section, but without the conodonts, bryozoans, corals, and echinoderms.

4. A dolomitic sandstone (unit 21, Section I) 20 feet below the top of the formation along the Rampart Range road. A few phosphatic shells of linguloid-like brachiopods were found.

The brachiopods found in units 2 and 12 include species of *Chonetes* and *Dictyoclostus* common in the Pennsylvanian but not particularly diagnostic. The ostracods and conodonts are abundant and well preserved.

The ostracod fauna includes species of the following genera: *Bairdia*, *Cavellina*, *Healdia*, *Geisina*, *Monoceratina*, *Glyptopleura*, *Amphissites*, *Kirkbya*, *Hollinella*, and *Pseudoparaparchites*. The writer tentatively identified twelve of these Glen Eyrie ostracods with species previously described, which together are diagnostic of early or middle Pennsylvanian sediments. Other ostracods in the fauna have not been described.

The following four genera of conodonts, including at least six species, were identified: *Idiognathodus*, *Streptognathodus*, *Cavusgnathus*, and *Spathodus*. No one of the six species is particularly diagnostic by itself, but as a fauna they indicate that the Glen Eyrie is Des Moines or younger in age.

The position of the Glen Eyrie and Fountain formations in the Pennsylvanian system as indicated by the Glen Eyrie fauna is discussed in detail under Age of Glen Eyrie and Fountain Formations.

## FOUNTAIN FORMATION

### GENERAL FEATURES

The Fountain formation consists of a thick series of red irregularly bedded coarse-grained arkosic sandstones and conglomerates sparsely interbedded with thin shales and locally fossiliferous limestones. The Fountain rests unconformably on older formations at all exposures around the southern end of the Front Range except those in the Manitou embayment where it conformably overlies the Glen Eyrie formation. The Fountain is overlain with apparent conformity by the Lyons sandstone throughout the area considered in this paper.

The greatest known thickness of the Fountain formation is at the type locality. Nearly 4,400 feet of red sandstones and conglomerates are exposed in the valley of Fountain Creek between Manitou and West Colorado Springs (Fig. 2). Paleozoic exposures are cut out for a distance of about 10 miles along the mountain front by overthrusting along the Cheyenne Mountain thrust fault (Fig. 1). As a result Fountain exposures in the Manitou embayment are separated from those in the southwestern quarter of the quadrangle. In the latter area the thickest surface exposures are of the order of 1,500 feet. A thickness of 1,287 feet of Fountain is present in the valley of Little Bear Creek (Fig. 3), 1,470 feet in the valley of Turkey Creek, and 1,490 feet across the valley of Sand Creek near the western edge of the quadrangle. Information from wells drilled near the out-

## SECTION II

SECTION THROUGH GLEN EYRIE AND FOUNTAIN FORMATIONS IN VALLEY OF FOUNTAIN CREEK AND TRIBUTARIES, SECS. 3, 4, 5, AND 10, T. 14 S., R. 67 W., EL PASO COUNTY, COLORADO

Over-all thicknesses determined by plane-table traverse; individual units measured by Jacob-staff traverse at time formations were described

| *Description* | *Thickness in Feet* | |
|---|---|---|
| | *Of Unit* | *To Bottom of Formation* |
| LYONS SANDSTONE—PERMIAN? | | |
| Sandstone, red, massive, medium- to fine-grained | | |
| FOUNTAIN FORMATION | | |
| 46. Sandstone, red, thinly bedded, medium- and coarse-grained | 5.0 | 4,370.0 |
| 45. Sandstone, red, poorly exposed | 160.0 | 4,365.0 |
| 44. Sandstone, red with some gray beds, arkosic, slightly conglomeratic | 265.0 | 4,205.0 |
| 43. Sandstone, red and gray, arkosic, poorly exposed | 400.0 | 3,940.0 |
| 42. Sandstone, red and gray, coarse-grained, arkosic | 15.0 | 3,540.0 |
| 41. Sandstone, gray, thinly bedded, coarse-grained, arkosic, interbedded with red thinly bedded fine-grained micaceous sandstone | 15.0 | 3,525.0 |
| 40. Sandstone, red, thin-bedded, massively weathering, coarse-grained, arkosic, poorly exposed | 240.0 | 3,510.0 |
| 39. Sandstone, red, thin-bedded, massively weathering, coarse-grained, arkosic, irregularly conglomeratic; a few cobbles as large as 6 inches in diameter | 210.0 | 3,290.0 |
| 38. Sandstone, red, thin-bedded, massively weathering, coarse-grained, arkosic | 460.0 | 3,080.0 |
| 37. Sandstone, red, massive, coarse-grained, irregularly conglomeratic, arkosic; quartz and quartzite predominant among pebbles and cobbles | 475.0 | 2,620.0 |
| 36. Sandstone, red, massive, coarse-grained, conglomeratic, arkosic; decomposed schist and biotite granite predominant among cobbles; upper 25 feet poorly exposed | 105.0 | 2,145.0 |
| 35. Sandstone, red, poorly consolidated, coarse-grained, irregularly conglomeratic, arkosic, poorly exposed | 280.0 | 2,040.0 |
| 34. Sandstone, red, coarse-grained, conglomeratic, arkosic, interbedded with maroon thin-bedded fine-grained micaceous sandstone and shale | 109.0 | 1,760.0 |
| 33. Sandstone, red, coarse-grained, irregularly conglomeratic, arkosic, poorly exposed | 145.0 | 1,651.0 |
| 32. Sandstone, red, massive, coarsely conglomeratic; cobbles and small boulders of quartz, quartzite, and decomposed granite | 10.0 | 1,506.0 |
| 31. Sandstone, red, thin-bedded, coarse-grained, irregularly conglomeratic, arkosic; cobbles as large as 4 inches in diameter | 60.0 | 1,496.0 |
| 30. Sandstone, red, massively bedded, coarse-grained, conglomeratic, arkosic. | 65.0 | 1,436.0 |
| 29. Sandstone, red, massive, coarse-grained, arkosic | 8.0 | 1,371.0 |
| 28. Sandstone, red, irregularly bedded, conglomeratic, arkosic, with stringers and lenses of silt and shale, poorly exposed | 190.0 | 1,363.0 |
| 27. Sandstone, mottled red and gray, irregularly bedded with lenses of cross-laminated sandstones, coarse-grained, conglomeratic, arkosic; sub-rounded to angular cobbles average 3 inches in diameter | 210.0 | 1,173.0 |
| 26. Sandstone, red, coarse-grained, coarsely conglomeratic, arkosic, interbedded with maroon fine-grained, shaly micaceous sandstone; rounded and angular cobbles dominantly of quartz and quartzite | 75.0 | 963.0 |
| 25. Sandstone, red, massive, coarse-grained, slightly conglomeratic, arkosic, interbedded with lenses of soft maroon shaly sandstone; rounded pebbles of granite predominate in conglomeratic fraction | 15.0 | 888.0 |
| 24. Sandstone, mottled red and white, massive, medium- and coarse-grained, arkosic | 10.0 | 873.0 |
| 23. Sandstone, red, massive— coarse-grained, conglomeratic, arkosic, with interbedded thin medium-grained arkosic sandstones, poorly exposed | 80.0 | 863.0 |
| 22. Conglomerate, red, massive, arkosic, interbedded with red and white thin-bedded fine-grained arkosic sandstones and black thin shales | 55.0 | 783.0 |
| 21. Sandstone, red, loosely consolidated, coarse-grained, arkosic | 10.0 | 728.0 |

SECTION II—(*continued*)

| Description | Thickness in Feet: Of Unit | Thickness in Feet: To Bottom of Formation |
|---|---|---|
| 20. Siltstone, red, thin-bedded, micaceous, with thin stringers of white medium- and coarse-grained arkosic sandstone | 40.0 | 718.0 |
| 19. Sandstone, pink and white, thin-bedded, coarse-grained, arkosic | 26.0 | 678.0 |
| 18. Sandstone, red, massively and irregularly bedded, coarse-grained, slightly conglomeratic arkosic; lower 15 feet poorly exposed | 48.0 | 652.0 |
| 17. Sandstone, gray, irregularly bedded, coarse-grained, arkosic | 15.0 | 604.0 |
| 15. Unexposed | 14.0 | 589.0 |
| 15. Sandstone, red and white, massive, coarse-grained, slightly conglomeratic, arkosic | 22.0 | 575.0 |
| 14. Shale, red, fissile, sandy, with thin beds of shaly sandstone | 5.0 | 553.0 |
| 13. Sandstone, red and gray, irregularly bedded, coarse-grained, conglomeratic, arkosic | 46.0 | 548.0 |
| 12. Sandstone, gray, poorly consolidated, coarse-grained, arkosic | 38.0 | 502.0 |
| 11. Sandstone, red, evenly bedded, coarse-grained, arkosic, with thin stringers of cross-bedded sandstone and of conglomerate | 57.0 | 464.0 |
| 10. Conglomerate, red and gray, arkosic; angular and rounded fragments of cobble and boulder size; quartz and quartzite slightly predominant over granite | 4.0 | 407.0 |
| 9. Sandstone, red and white, massive, coarse-grained, conglomeratic, with thin beds, of gray fine-grained micaceous sand; conglomeratic fraction consists of angular fragments thinly scattered along bedding surfaces | 35.0 | 403.0 |
| 8. Sandstone, red and gray, poorly consolidated, coarse-grained, arkosic, poorly exposed | 95.0 | 368.0 |
| 7. Sandstone, red and gray, thick-bedded, medium- and coarse-grained, arkosic, interbedded with very coarse conglomerate | 112.0 | 273.0 |
| 6. Unexposed | 10.0 | 161.0 |
| 5. Sandstone, mottled purple, red and white, massively and irregularly bedded, medium- to coarse-grained, conglomeratic, arkosic; topped by 6-inch layer of white coarse-grained calcareous sandstone | 23.0 | 151.0 |
| 4. Sandstone, red, well consolidated, coarse-grained, slightly conglomeratic, arkosic | 4.0 | 128.0 |
| 3. Sandstone, red, thick-bedded, coarse-grained, slightly conglomeratic, arkosic; near the top, two bedding surfaces are thinly veneered by subangular pebbles and small cobbles | 65.0 | 124.0 |
| 2. Conglomerate, red, coarse, arkosic; large subangular cobbles of granite and smaller rounded cobbles of quartz and quarztite constitute most of the bed | 2.0 | 59.0 |
| 1. Sandstone, mottled white and purple, thick-bedded, coarse-grained, slightly conglomeratic, arkosic; interbedded with thin stringers of purple and red fissile silty micaceous shale | 57.0 | 57.0 |
| GLEN EYRIE FORMATION | | |
| 9. Sandstone, bright yellow, coarse- to medium-grained | 6.0 | 122.0 |
| 8. Shale, gray and yellow (no fossils found) | 7.0 | 116.0 |
| 7. Sandstone, purple and white, coarse-grained, slightly arkosic | 7.0 | 109.0 |
| 6. Shale gray and black, with thin stringers of gray medium-grained arkosic sandstone in upper 10 feet | 28.0 | 102.0 |
| 5. Sandstone, gray, fine- to medium-grained, shaly | 4.0 | 74.0 |
| 4. Sandstone, yellow, hard, thinly bedded, medium-grained | 5.0 | 70.0 |
| 3. Shale, gray and black, with thin beds of yellow medium-grained slightly arkosic sandstone; poorly exposed | 40.0 | 65.0 |
| 2. Sandstone, red and white, slightly conglomeratic, slightly arkosic | 15.0 | 25.0 |
| 1. Shale, black, gray, and yellow, interbedded with thin stringers of yellow medium-grained sandstone and of dark red to black siliceous hematite | 10.0 | 10.0 |
| MADISON LIMESTONE—MISSISSIPPIAN | | |
| Limestone, much weathered, possibly brecciated, in angular unconformity under overlying Glen Eyrie shales | | |

crop and farther eastward indicates that the Fountain thickens markedly toward the east. However, none of the wells has penetrated a section thicker than that exposed at the type locality.

Section II of the Fountain and Glen Eyrie formations was measured and described in and near the type locality of the Fountain.

### CONGLOMERATES OF FOUNTAIN

In the present paper the use of the name "conglomerate" has been applied to include beds composed so predominantly of fragments of pebble size or larger that the poor sorting implied by the name "conglomerate" is not readily apparent. Such application is desirable because of the lateral changes of texture which these pebble beds undergo. Many of them become definite conglomerates, a few grade laterally into sandstones.

*General lithologic description.*—There are major lithologic similarities among the conglomerates of the Fountain. They are all arkosic to some degree, cleavage fragments of feldspar ranging in diameter from 4 inches to that of fine sand. Quartz fragments are of all shapes and degrees of roundness, and many of them are larger than the associated fragments of feldspar. In many of the conglomerates fragments of granite and quartzite are nearly as abundant as those of feldspar and quartz.

Fragments of quartzite are both rounded and angular and the coarse particles range in size from pebbles to small boulders. Granite fragments are subangular to rounded and most of them appear to be of a finer-grained variety than that from which the arkosic material was derived. Many of the fragments of coarser-grained granite are somewhat disintegrated. At most exposures the less weathered granite and other crystalline rocks show no correlation between size and degree of rounding. In the same conglomeratic bed angular and rounded boulders and angular and rounded pebbles, all of the same type of granite occur side by side. Apparently weathering at the source area was at least as important in controlling shape and size as was wear during transport.

Chert, schist, gneisses, and some basic igneous rocks are locally abundant. Most chert fragments are subangular to rounded and are seldom larger than small cobbles. Nearly all the schist, gneiss, and basic igneous rock fragments are moderately rotten, fairly well rounded, and generally less than 10 inches in diameter.

*Conglomerates of especial significance.*—The local distribution of chert fragments within the lower few hundred feet of the formation is closely related to the distribution of formations underlying the Fountain. The source of the abundant angular to subrounded pebbles and cobbles of red, yellow, and white chert in these conglomerates must have been the Manitou dolomite and the Madison limestone both of which contain nodules and lenses of chert. The other known pre-Pennsylvanian formations of the Front Range are chert-free.

The Manitou and Madison formations are discontinuous and absent for long distances along the mountain front south of the Manitou embayment. It is along this part of the mountain front that chert is most abundant in the lower conglomerates of the Fountain. In the southwestern part of the Colorado Springs Quadrangle the Manitou is better preserved than the overlying Madison, which north of Red Creek crops out only in the valley of Little Bear Creek. The Madison is more continuous south and west of Red Creek into the Canon City embayment. Prior to Fountain time the Madison was undoubtedly more extensive than at present. Molds and casts of Mississippian spiriferoid brachiopods are found in chert pebbles and cobbles of the lower conglomerates even where the Fountain rests on Manitou or pre-Cambrian rocks. Along the mountain front north of Colorado Springs pebbles and boulders of chert, some of which contain Mississippian fossils, have been found near the base of the Fountain; throughout most of this distance the Fountain is in contact with pre-Cambrian crystalline rocks.[11]

In the Manitou embayment the Manitou and Madison formations are present in their thickest development between Canon City and the Colorado-Wyoming State line. Here chert is absent from Fountain conglomerates as contrasted to localities south of the embayment where fragments of chert outnumber those of quartz, feldspar, and quartzite.

In the valley of Little Bear Creek some of the basal massive conglomeratic beds of the Fountain contain scattered cobbles of rhyolite up to 4 or 5 inches in diameter. Distribution of this rhyolite is restricted to Little Bear Creek valley and its tributary, Deadman Canyon. Stratigraphically the occurrence of rhyolite is limited to approximately the basal 400 feet of the formation. The eastward subsurface extent of the rhyolite-bearing beds has not been determined.

The only known sources for this rhyolite are the pre-Cambrian intrusive bodies along the Paleozoic-pre-Cambrian contact just west of the Fountain outcrops in which it occurs (Fig. 3). All exposures of rhyolite-bearing beds are less than $\frac{3}{4}$ mile from the outcrops of these intrusive bodies.

Just south of the divide between Little Fountain and Little Bear creeks Fountain overlies fresh rhyolite. Almost equally fresh fragments of the latter are incorporated in the basal conglomerates of the Fountain. Southward decomposed rhyolite becomes more abundant in the conglomerates and fresh fragments rarer. At the mouth of the southernmost canyon of the Little Bear Creek drainage Manitou dolomite overlies rhyolite which is weathered and decomposed to considerable depth.

At a few exposures Fountain conglomerates include cobbles of several varieties of red sandstone unlike any known from pre-Fountain formations. On the south side of Little Bear Creek a conglomerate 1,130 feet above the base of the formation contains rounded cobbles of red fine-grained sandstone that appears identi-

[11] Willis T. Lee, "Correlation of Geologic Formations between East-Central Colorado, Central Wyoming, and Southern Montana," *U. S. Geol. Survey Prof. Paper 149* (1927), p. 5.

cal with those of the upper Fountain and Lyons formations. Even the bleached spots so characteristic of these sandstones are present on the largest cobbles which range up to 7 inches in diameter. In an un-named gulch near the foot of the Crystal Park Toll Road (Fig. 2) rounded and subrounded cobbles and small boulders of red medium-grained arkosic sandstone are not uncommon in the coarse conglomerates exposed. These cobbles appear identical in composition with part of the matrix of the conglomerates and with many of the sands found both higher and lower in the formation.

Another variety of Fountain conglomerate is exposed in a bank of the West Fork of Red Creek approximately one half mile above the junction with Red Creek (Fig. 3). A channel cut in thin-bedded sandstone was filled by coarse almost unbedded conglomerate containing angular and rounded cobbles as large as 4 inches in diameter. Calcareous nodules, worn and broken but identical with the impure nodular limestones of the Fountain, are particularly abundant among these cobbles.

Sorting of a peculiar kind is exhibited in a bed 850 feet above the base of the Fountain in the Manitou embayment. A massive sandstone is made conglomeratic by the presence of abundant well rounded fragments of medium-grained granite. Nearly all the fragments are of a size between 15 and 25 millimeters. Larger subrounded pebbles of quartz are present but are very rare.

*Distribution of conglomerate within Fountain.*—In the two sections of the Fountain measured and described, conglomerates make up a smaller proportion of the total thickness than would be estimated from casual observation. In the Manitou embayment section conglomerates comprise approximately 15 per cent of the total thickness; along Little Bear Creek they comprise approximately 26 per cent of the section. In the accompanying graphs (Fig. 4) the similarity of vertical distribution of conglomerate in the two sections is obvious. For the Little Bear Creek section the percentage of conglomerate per 100 feet is shown; for the Manitou embayment section, slighly more than three times as thick, the unit interval is 300 feet. Vertical and horizontal scales have been adjusted to facilitate qualitative comparison. The major difference in the two graphs is the contrast between the lower 200 feet of the Little Bear Creek section and the equivalent lower 600 feet in the Manitou embayment. The lower proportion of conglomerate in the latter is in accord with the gradational change from Glen Eyrie shales and sandstones to the coarser Fountain sediments.

*Stratification of conglomerates.*—Conglomerates in the Fountain commonly occur as irregular lenses of limited extent, as pockets which are definitely parts of channel fillings, and as zones within massive beds of arkosic sandstone. These latter are integral parts of the beds in which they occur and have no effect on the bedding. There is no evidence of scouring at their bases as there is at the base of an obvious channel filling. Individual beds of conglomerate which stand out as definite units and have an observable lateral extent of more than a few hundred yards along strike are almost entirely confined to the lower 700 feet of the Foun-

tain in the Manitou embayment. As indicated in the preceding section there is, within thick units of the formation, a marked similarity in the development of conglomerate in different localities. However, this similarity does not apply to individual beds.

Within the lower 700 feet of the Fountain in the Manitou embayment single beds of conglomerate may be traced along canyon walls for distances of 400 yards or more, the limits being set by the exposures rather than by the beds themselves. Throughout the extent of exposure these and some of the associated beds of sand-

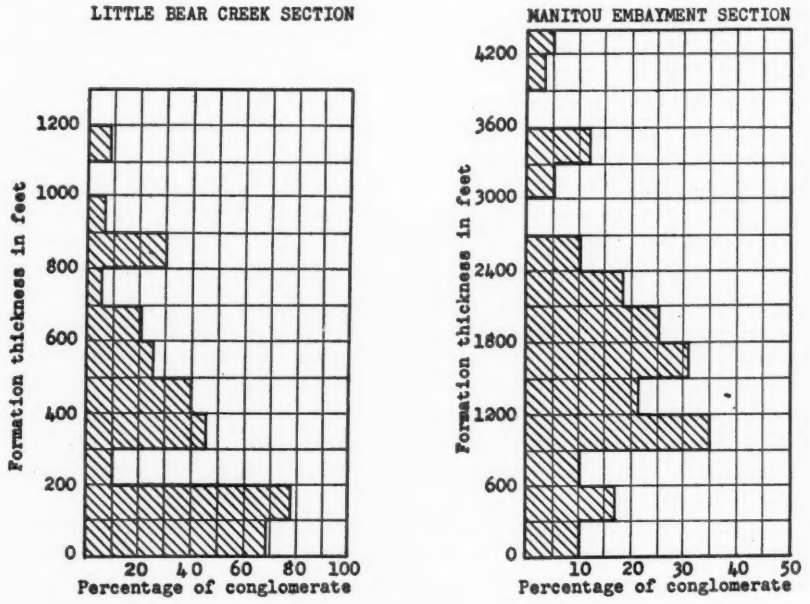


FIG. 4.—Comparison of vertical distribution of conglomerate in two sections of Fountain formation 14 miles apart along mountain front.

stone and shaly sand maintain nearly constant thicknesses. It is probable that the gradational change from Glen Eyrie to Fountain was responsible for this regularity of bedding in the lower Fountain.

In the same part of the section are a few conglomerate stringers marking the contacts between massive irregularly bedded sandstones. These stringers consist of veneers of subangular pebbles and cobbles $\frac{1}{2}$–5 inches in diameter. They are spread over rather even surfaces which at places truncate the bedding planes of the underlying sandstones. At no point along the exposures was a stringer observed to be more than one fragment thick; at no point does more than one pebble or cobble separate the underlying sandstone from the one above. Inequidimen-

sional fragments are oriented with long dimensions paralleling the surfaces on which they lie.

Two such stringers, approximately 105 and 110 feet above the Glen Eyrie-Fountain contact, are exposed for a distance of a little more than 100 feet on the divide east of the mouth of Williams Canyon (Fig. 2). Within the limits of this exposure the thinness of the stringers and the regularity of the underlying surfaces remain constant. In exposures along the east wall of the "cliff-dwellings" canyon, approximately 350 feet above the Glen Eyrie-Fountain contact, similar conglomerate stringers occur along the bedding surfaces of irregularly bedded poorly sorted sandstones. These stringers resemble those aforedescribed in thinness and size of fragments, but lie along irregular surfaces and are truncated by overlying beds. The maximum observed extent of these latter stringers is approximately 40 feet along the exposure.

Of the conglomerates studied in the Fountain it was only in these "veneer" stringers that any arrangement of flattened fragments was noted. In the thicker conglomerates and conglomeratic zones flattened fragments are not uncommon but there is complete absence of observable orientation. In no part of the Fountain, "veneer" conglomerates included, is there evidence of imbricate structure.

Aside from the stringers described, the comparatively well bedded conglomerates, and the conglomeratic zones within massive beds of arkosic sandstone, deposition of conglomerates was controlled largely by the configuration of the surface on which the sediments were laid down. Most of the conglomeratic bodies occur as more or less isolated pockets and lenses occupying channels scoured in the underlying sediments. Few of these pockets and lenses are thicker than 8–10 feet. Their wedging-out between beds of sandstone, between limestone and sandstone beds, or between other conglomeratic beds may be seen at almost every exposure.

*Detailed descriptions of conglomerates.*—Several of the lower Fountain conglomerates were studied in detail in the field for the purpose of obtaining more definite information concerning size ranges, shapes, composition, and possible orientation of fragments. Selection of subject beds for the study was more or less at random. The following three summaries are presented as characteristic but not necessarily typical of Fountain conglomerates.

1. A massive basal conglomeratic sandstone in the southernmost canyon tributary to Little Bear Creek (Fig. 3). The exposure is an eroded surface nearly paralleling the bedding of the formation. The matrix of the conglomerate is poorly sorted, varying from sand to fine gravel, and enclosing pebbles and cobbles up to 6 or 7 inches in diameter. Fragments between 1 inch and 4 inches in diameter comprise at least 80 per cent of the coarse fraction. Boulders are very rare. Inasmuch as fragments larger than 1 inch in diameter constitute a very small part of the entire bed a numerical count of fragments as to size and composition was not made.

| *Composition—in Order of Decreasing Abundance* | *Shape* | *Condition* |
|---|---|---|
| Quartz and quartzite | Subangular to rounded; rarely spherical | Fresh |
| Chert | Flattened and subangular. A few smaller fragments equi-dimensional, subangular to subrounded | Fresh |
| Granite and pegmatite | Angular to rounded | Fresh and partly decomposed |
| Gneiss and schist | Flattened | Decomposed |
| Rhyolite | Equi-dimensional, rounded | Decomposed |

Observation of the granite and pegmatite fragments indicated no apparent correlation between degree of rounding and decomposition. The scattered rhyolite fragments are so much decomposed that their shape must be regarded as meaningless. Some of them have been indented and their shape appreciably changed by other fragments with which they are in contact. Although flattened fragments of chert, gneiss, and schist are rather abundant there is no development of imbricate structure.

2. Very coarse lower Fountain conglomerate exposed in an un-named gulch near the foot of the Crystal Park Toll Road (Fig. 2) at the south edge of the Manitou embayment. In a general way the conglomerates exposed in this gulch are the equivalents of those in unit 27 of Section II. Boulders up to 2 feet in diameter are present but are not abundant. The following count was made over one square yard of exposure.

| *Size (Diameter in Inches)* | *Description* | *Number of Fragments* |
|---|---|---|
| 8 | Subangular partly disintegrated granite | 1 |
| 6 | Angular milky quartz | 2 |
| 5 | Angular partly disintegrated granite | 2 |
| 5 | Rounded red shaly arkosic sandstone (stringers of identical material in matrix) | 1 |
| 4 | Cleavage fragments of feldspar | 1 |
| 3 | Subangular red shaly arkosic sandstone | 1 |
| 2 | Angular and subangular quartz and quartzite pebbles and cobbles. | 108 |
| (Average) | A few are flattened but there is no imbrication | |
| 2 | Angular to subrounded granite pebbles and cobbles | 18 |
| (Average) | | |
| 1–2 | Angular soft red shaly siltstone | 11 |
| 1–2 | Angular cleavage fragments of feldspar | 28 |

In the foregoing count fragments more than 1 inch in diameter constitute 60 per cent of the entire exposure. There is a considerable break in size range less than 1 inch, and the remaining 40 per cent is considered to be poorly sorted matrix.

3. The following count was made over one square yard of exposure at the same locality as count number 2 but 100 feet lower stratigraphically.

| *Size (Diameter in Inches)* | *Description* | *Number of Fragments* |
|---|---|---|
| 12 | Angular partly disintegrated medium-grained granite | 1 |
| 9 | Angular biotite schist | 1 |
| 8 | Subrounded red medium-grained arkosic sandstone | 1 |
| 5 (Average) | Angular to subrounded quartz | 12 |
| 5 (Average) | Subangular to rounded partly disintegrated coarse-grained granite | 6 |
| 3 | Cleavage fragments of feldspar | 7 |
| 2 | Subangular to rounded quartz | 48 |
| 2 | Subrounded partly disintegrated granite | 5 |
| 1 by 3 | Flattened biotite schist. No imbrication | 6 |

In the foregoing count fragments more than 1 inch in diameter comprise approximately 80 per cent of the entire exposure. The poorly sorted matrix is composed primarily of subrounded quartz fragments, a little granite in small rounded fragments, and a smaller amount of angular feldspar, all considerably less than $\frac{1}{2}$ inch in diameter.

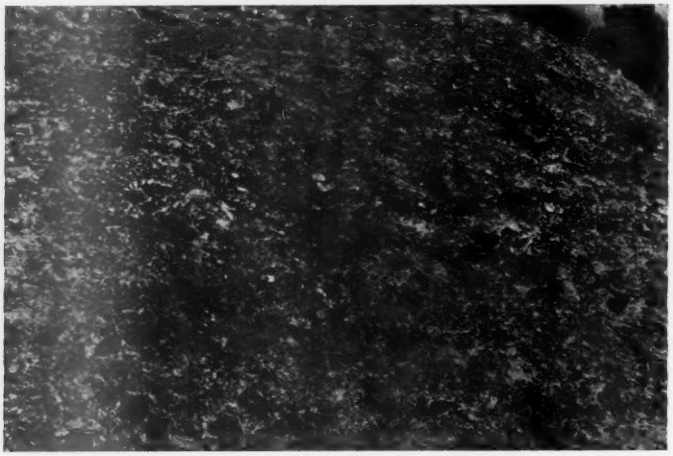

FIG. 5.—Boulder conglomerate in lower Fountain. Light-colored granite boulder left of center is 22 inches in diameter. Exposure is in un-named gully west of Crystal Park Toll Road in southern part of Manitou embayment.

### SANDSTONES OF FOUNTAIN

There is no sharp differentiation between many of the sandstones and conglomerates of the Fountain; coarse-grained arkosic sandstones grade laterally into conglomeratic sandstones and conglomerates, and the same gradation may be observed vertically. As mentioned previously sandstones and conglomerates are interbedded throughout the formation and, as a result, the stratigraphic characteristics of the conglomerates are essentially duplicated in the sandstones.

Comparatively well bedded sandstones occur in the lowermost part of the Manitou embayment section; above them discontinuous bedding, definite channel fillings, and irregularly cross-bedded zones predominate. These cross-bedded zones are the most discrete of the sandstone units in that they almost always occupy recognizable erosion troughs and are marked by thin sharp laminae of rather uniform thickness.

In general Fountain sandstones are red, arksoic, medium- to coarse-grained, and poorly sorted. The red color is primarily a result of the presence of iron oxides which may be only a stain on the surface of grains or may occur interstitially as cementing material. Cut and ground surfaces of typical sandstones and matrices of conglomerates revealed colorless, white, or pink feldspar, but none red enough to contribute appreciably to the prevailing color of the formation. Zones which are dependent on feldspar for color appear almost white in contrast to the red layers above and below. Red pigment has probably been removed from some of the thin white beds and parts of beds. Although many of the light-colored sandstones are calcareously cemented this relationship of color to cementing material is not constant. Calcareously cemented sandstones are almost totally absent at the type locality of the formation, although there are several light-colored and white sandstones in the section. Quartz is the dominant mineral in all the sandstone beds and conglomerate matrices and constitutes the larger grains of the poorly sorted sandstones.

Following are hand-lens and thin-section descriptions of a typical Fountain sandstone.

Under the hand lens 90 per cent or more of the rock appears to be composed of poorly sorted subrounded to angular fragments of pink feldspar and quartz 2 millimeters or less in diameter. There is a small number of larger cleavage fragments of feldspar ranging from 2 to 10 or 12 millimeters in diameter and a very few rounded fragments of chert or jasper of about the same size. The rock is well indurated.

Thin sections reveal that angular fragments of microcline perthite constitute approximately 35 per cent of the rock. Plagioclase feldspar is rare. Subrounded to angular quartz makes up most of the remainder of the specimen. There are also small sparsely scattered fragments of partly altered biotite. Black, opaque material occurring interstitially is the iron oxide which gives the sandstone its red color.

The porosity of the specimen studied in thin section is very low as a result of the compaction of the poorly sorted irregularly shaped fragments and the interstitial fillings of silty and clayey material and iron oxides. Some very irregularly shaped feldspar fragments are fitted together in a manner resembling the intergrowth of adjacent crystals in an igneous rock; between some of these there are very thin layers of sericite.

In the Manitou embayment coarse-grained sandstones similar to that described prevail to the top of the Fountain. The result is a sharp lithologic change

to the finer-grained non-arkosic sandstones of the Lyons formation.

Throughout the sandstones of the lower 1,200 feet of the Little Bear Creek section most of the quartz grains over 1 millimeter in diameter are subangular to well rounded, and a small number are frosted or pitted. Smaller grains are more angular. In this part of the section most of the quartz is colorless or gray, rarely pink. With the exception of those which are frosted or pitted, surfaces of most of the quartz grains are stained red.

Most of the feldspar in these sandstones occurs as angular to subangular cleavage fragments. Feldspar grains constitute 20–40 per cent of the total in the sandstones of the lower 1,200 feet of the formation along Little Bear Creek, practically all the remainder being quartz. The only other mineral of any consequence is mica which makes up as much as 10 per cent of the total in the most micaceous sandstones. Nearly all the recognizable mica is biotite occurring in flakes 1–2 millimeters in greatest dimension.

With few exceptions the sandstones of the lower 1,200 feet of the Little Bear Creek section are poorly sorted. The general range of grain sizes is between 0.2 and 3.0 millimeters with finer material occurring interstitially and larger grains up to 6.0 millimeters or more, tending to make many of the sandstones conglomeratic. In this lower part of the formation a few of the sandstones are comparatively well sorted, the grains ranging between 0.2 and 0.5 millimeter in diameter; grains as large as 2.0 millimeters are extremely rare. Interstitial material is commonly silty or clayey and rich in iron oxide. Calcareously or siliceously cemented zones are rare.

Southward from the embayment the upper 200 feet of the Fountain includes a number of sandstones similar to those of the Lyons. Feldspar grains in most of these constitute less than 10 per cent of the mass, and the dominant grain size is near 0.25 millimeter. Rounded, pitted, and frosted grains are no more abundant than in the lower part of the formation. Clayey and silty interstitial material is less abundant, and induration by calcareous or siliceous cements is the rule rather than the exception.

### SHALES OF FOUNTAIN

As has been previously mentioned shales are rare in the Fountain and their distribution within the formation is erratic. In the Manitou embayment section definite shale beds were not found higher then 700 feet above the base of the Fountain. Thin black shale beds occur at about this stratigraphic position in the west wall of Quarry Canyon (Fig. 3). They are exposed for nearly 400 yards along the canyon walls and are evenly interbedded with massive sandstones for the entire dstance. Poor exposures up and down the canyon prevent the determination of their total extent. Below these Quarry Canyon exposures the few shales present are limited in areal extent, some appearing as lenses and others obviously occupying narrow erosion channels. Pockets of arkosic mudstone occur sparsely throughout the upper part of the formation.

Along Little Bear Creek, however, shale beds occur throughout the section; their combined thickness is approximately 90 feet of the total of nearly 1,300 feet. The thickest individual bed exposed is less than 6 feet thick; many are less than 1 foot in thickness. With the exception of the topmost beds Fountain shales are highly micaceous, red, and ordinarily somewhat sandy. Some zones are thinly laminated, but in others lamination is almost absent; increase in sand content accompanies poor development of bedding. A few of the layers whose topographic expression is like that of shale are actually red mudstones containing as much as 10 per cent of recognizable feldspar. Shales that are only slightly micaceous are exposed in the banks of Little Bear Creek near the Fountain-Lyons contact. One of these, about 1 foot thick, is purple and platy and contains no mica flakes large enough to be visible under a hand lens.

Thin shales are interbedded with both conglomeratic and non-conglomeratic sandstones. In a few exposures shales are in direct contact with coarse conglomerates. As a result of this interbedding with irregularly bedded sandstones and conglomerates most of the shales are of limited areal extent.

#### LIMESTONES OF FOUNTAIN

*Distribution and structural features.*—No limestones were found in the Fountain formation within the Manitou embayment. This absence of limestones and almost total absence even of calcareous sandstones is one of the major differences between the formation at the type locality and exposures at the south.

Thin limestones, most of them less than 3 feet thick, are irregularly distributed throughout the Fountain of the southwestern part of the quadrangle. The lowest of these, stratigraphically, is the "Red Creek"[12] limestone which crops out in the valley of Red Creek within 250 feet of the base of the formation. The highest is the "Contact" limestone used as the key bed for mapping the Fountain-Lyons contact, and which occurs in the upper part of the 100-foot interval considered the transition zone between Fountain and Lyons. Between the "Red Creek" and "Contact" limestones, particularly across the Red Creek anticline (Fig. 3), isolated limestone outcrops and detritus from thinly covered beds indicate the presence of at least four additional limestones within the main body of the formation.

Some of these Fountain limestones are massively bedded, others are thin-bedded and weather out in slabs. At a few places the thin-bedded limestones are folded on a small scale, the amplitude of some of the folds being as much as 1½ feet with lengths up to 3 feet. This particular type of irregular bedding is probably a result of pene-contemporaneous sliding or slumping along the surface on which deposition occurred. The nature of the bedding is not constant; a single limestone may be massive, thin-bedded, and folded at different places within a few hundred yards along the outcrop.

[12] The names applied to this and other Fountain limestones are for convenience of reference only and are not proposed as additions to the stratigraphic nomenclature.

There is a certain constancy in the relationship between Fountain limestones and the beds with which they are associated. At nearly any exposure of limestone there is an underlying nodular impure limestone or calcareous siltstone and sandstone or interbedded layers of both. Below this may occur any of the sedimentary rock types found in the formation; thinly cross-bedded sandstone is most common. Most of the limestones are unconformably overlain by conglomeratic sandstones. At some exposures evidence of erosion consists of a slight irregularity of the upper surface of the limestone together with cracks and fissures in the limestone which have been filled with clastic material. At other exposures the limestones have been distinctly channeled; some of these channels are as much as 5 or 6 feet deep (below the upper surface of the limestone) and extend into the underlying nodular layer.

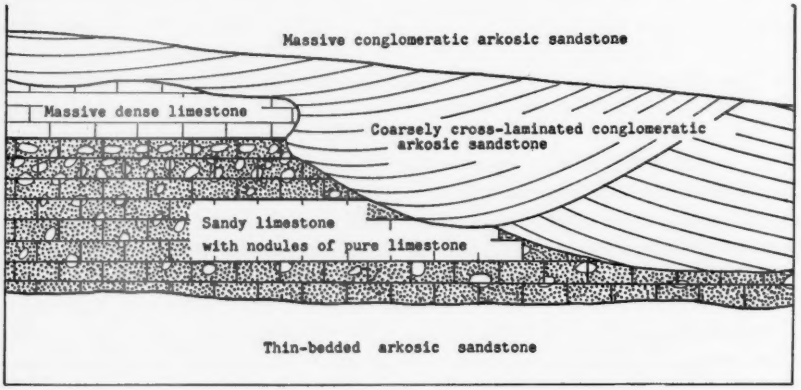
Massive conglomeratic arkosic sandstone
Massive dense limestone
Coarsely cross-laminated conglomeratic arkosic sandstone
Sandy limestone with nodules of pure limestone
Thin-bedded arkosic sandstone

FIG. 6.—Section of exposure of lower Fountain limestone, 500 feet above base of formation, illustrating typical relationships of limestone zones to overlying and underlying sandstones. Exposure is slightly south of midway point between Little Turkey and Turkey creeks west of Highway No. 115. Horizontal and vertical scale: 1 inch equals 9.5 feet.

In spite of erosion these limestones are distinctive among the other Fountain sediments in the magnitude of their areal extent. The exception is the "Red Creek" limestone which may be traced along the outcrop for less than $\frac{1}{4}$ mile. Most of the other Fountain limestones may be followed and mapped for distances up to several miles (Fig. 3). As indicated on the map the limestones actually outcrop over much of this distance, and their one-time presence is inferred for the remainder by the continuity of underlying nodular zones.

*Lithologic descriptions.*—Thin sections were prepared from seven different specimens of the limestones. Four of these were from scattered exposures along the "Contact" limestone; two were from the "Hart" limestone, or its near equivalent (Fig. 3), approximately 1,000 feet above the base of the formation; one was from the "Red Creek" limestone.

All specimens of the dense to lithographic varicolored "Contact" limestone are composed of microcrystalline calcite except where cavities have been filled by larger calcite crystals. Some of these cavities are partially or completely outlined by opaque to dark brown material. There are sparsely scattered grains of quartz present in three of the four specimens. Two of the four thin sections include well preserved cross sections of ostracod carapaces, in which the spaces between the valves are filled with large calcite crystals as are the cavities in the limestone. It is probable that the cavities, the crystals contained in them, and the carapace enclosed crystals are of secondary origin. Where shells protrude into crystal-filled cavities the cavity crystals, the preserved shell, and the crystals within the shell are all in the same optical orientation.

A specimen of lithographic gray "Hart" (?) limestone from the west flank of the Red Creek anticline appeared only slightly different in thin section from those of the "Contact" limestone. There are anhedral quartz grains in some of the calcite filled cavities but the single section included no fossil remains. A thin section of the pink sandy "Hart" limestone, as it occurs on the east flank of the anticline, is composed of about 70 per cent microcrystalline calcite and 30 per cent small angular quartz grains and rare fragments of plagioclase feldspar. The single specimen was not fossiliferous. At an outcrop in the East Fork of Red Creek near the Colorado Petroleum, Inc. Hart No. 1 location, this limestone contains large branching concretionary structures.

Thin sections of the red crystalline "Red Creek" limestone reveal it to be composed of uniformly and finely crystalline calcite with considerable ferric oxide among the crystals. A very few angular quartz grains are present. The numerous sections of foraminifera and a few of gastropods are opaque and red, apparently preserved as ferric oxide. A few of the larger shell sections, probably brachiopod remains, have been replaced by secondary calcite; the crystals of these preserved shells are in perfect optical orientation with the crystals of the surrounding limestone.

Aside from the sandy phases of the "Hart" limestone this "Red Creek" limestone contains the highest proportion of impurities of all the samples collected. Several samples of the Red Creek bed were dissolved in hot hydrochloric acid. By weight the red fine insoluble residue (largely ferric oxide) from each sample amounted to between 9 and 10 per cent of the original. The insoluble residues from other Fountain limestones were in all tests less than 3 per cent by weight.

*Paleontology.*—Fossils were discovered in the "Red Creek" limestone in 1939 by students and staff attending Louisiana State University's Field Camp. Brachiopods, gastropods, bryozoans, pelecypods, and echinoderm plates, spines, and stems may be collected at the outcrop. As mentioned previously formaniniferal sections are revealed in thin sections of the limestone. The mega-fossils are none too well preserved but the writer has identified among the brachiopods: *Spirifer opimus*, *S. rockymontanus*, *Dictyoclostus portlockianus*, and *Derbya crassa*.

Ostracod sections, both longitudinal and transverse, are abundant in thin

sections of the "Contact" limestone. They are present in specimens collected from both the east and west flanks of the Red Creek anticline. Inasmuch as sections only are available no generic or specific identifications have been attempted. However, some of the longitudinal sections are very similar in outline to species of *Bairdia* and *Cavellina* found in the Glen Eyrie and transverse sections show the overlap of one valve over the other that is characteristic of these genera.

### CHERT OF FOUNTAIN

A massive bed of varicolored chert, approximately 1½ feet thick in its maximum development, is exposed on the west side of Red Creek between massive conglomeratic sandstones 400 feet above the base of the Fountain. Natural exposures of the chert are almost non-existent but it was discovered close to the surface in a few places between Red Creek and the next valley on the west (Fig. 3). The total extent along strike, as indicated by detrital material, is nearly a mile in a southwesterly direction from Red Creek. Toward the southwest the chert plays out in a zone of limestones and calcareous sandstones. There is no evidence to indicate that it is present east of Red Creek.

In all trenched exposures this chert bed is much fractured and broken which undoubtedly accounts for the absence of outcrops. Mapping of the bed was based on the distribution of detrital material. Broken pieces of the bedded chert are differentiated from fragments out of the conglomerates on the following bases: all are angular as contrasted to the rounded or subrounded shape of most fragments from the conglomerates; much of the bedded chert is blue or red as contrasted to the grays or browns of the conglomerate cherts; much of it has an opaline appearance not observed in the conglomerate fragments.

Thin-section study of this bedded chert reveals it be to composed largely of chalcedony, some of which is spherulitic, with a small amount of quartz. Small subhedral bodies of calcite are present along some of the cracks. There are also a few larger corroded bodies of calcite not associated with cracks and entirely encompassed by unfractured chalcedony.

The nature of this bedded chert and its field relationships strongly suggest that it is of secondary origin and has replaced some more soluble material. Its position between massive conglomeratic sandstones is not in accord with the theory of deposition as a silica gel on the floor of a quiet body of water. The presence of corroded calcite fragments within chalcedony and the association with calcareous beds both point to origin by replacement. The calcareous beds at the southwest in which the chert plays out suggest that it was limestone which was replaced.

### SEDIMENTARY STRUCTURES OF FOUNTAIN

*Irregularity of bedding.*—Irregular lenticular bedding is as striking a feature of the Fountain as is the red color. The limited areal extent of individual units of the formation has been described previously. However, it is desirable to emphasize again the fact that the bulk of the Fountain is an aggregate of interfingering

lenses. A few of these lenses are strictly depositional features but most of them obviously occupy eroded depressions, the channels of currents that were alternately eroding and depositing during Fountain time.

It is probable that the distinction which was made between pockets and lenses in describing the conglomerates is dependent on the relationship between present-day exposures and the channels in which deposition occurred. If the exposure face is perpendicular, or nearly so, to the axis of the channel the filling material appears a relatively narrow, pocket-like body. On the other hand if the exposure face is parallel, or nearly so, with the channel axis the channel filling appears as a more extensive relatively thin lens.

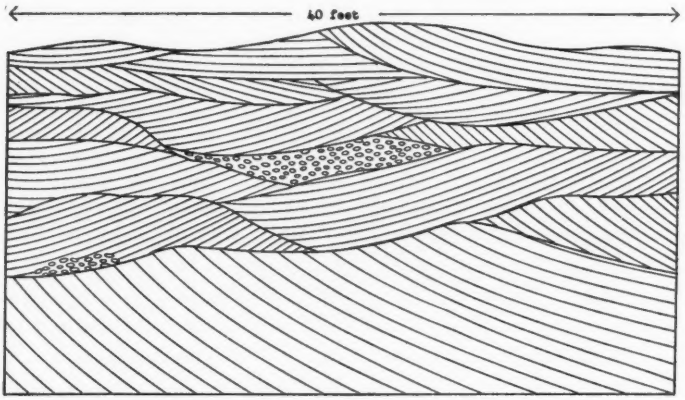


FIG. 7.—Section of exposure of "festoon cross-lamination" illustrating relationships of various sets of laminae to each other and to small conglomeratic bodies. Exposure is 150 feet below top of Fountain formation and ½ mile due south of Hitchrack Ranch reservoir.

The banks of most of the channels as indicated by the contacts between channel fillings and underlying scoured sediments were gently sloping, smooth, and rounded. In many exposures the lowermost of a series of cross laminae is spread evenly over these sloping bank surfaces. The rare examples of sharply cut banks are almost exclusively limited to channels cutting into or through one of the resistant limestone layers. In these channels the filling material is poorly stratified.

*Cross bedding.*—Cross bedding in the Fountain occurs on a variety of scales and in almost all types of clastic sediments, although it is best developed in medium- to coarse-grained fairly clean arkosic sandstones. In shaly sandstones cross bedding is less obvious because individual laminae do not stand out sharply. In some exposures the structure occurs in heavily conglomeratic sandstone, but individual laminae are not sharply outlined.

The cross bedding as observed in section and on dip-slope exposures strongly

resembles that which Knight[13] designated as "festoon cross-lamination." Comparison of the accompanying diagram and photograph with those of Knight clearly reveals the points of similarity.

Remarkably uniform thicknesses of between $\frac{1}{8}$ and $\frac{3}{4}$ inch are maintained by individual laminae throughout the extent of exposures like that illustrated in Figure 7. As indicated, small lenses of conglomeratic material are associated with the sets of cross laminae although the sands of the laminae themselves are seldom conglomeratic. Some of these conglomerates are obviously separated from the surrounding laminae by erosion surfaces; other appear to have been deposited just prior to the laminated sand, probably as small bars around and over which the laminae were built without appreciable halt in deposition. The best development of these thinly laminated structures is in the upper Fountain along Little Bear Creek and southward.

In many exposures laminae of the foregoing order of thickness are exposed for distances of 30–40 feet without exhibiting concavity. Their contact surfaces appear to be almost perfect planes the attitudes of which are definitely at variance with that of the formation. Field relationships suggest that these are simply fortuitous exposures of large scale examples of the "festoons." Laminae of this nature are common in exposures on the Red Creek anticline, and particularly in the Manitou embayment where concavity of cross laminae is rare.

Thicker laminae and thin beds from one fourth to 2 or 3 inches thick of poorly sorted slightly conglomeratic sandstones are developed in sets of slightly concave to plane cross laminations in some of the main hogback-forming units of the lower Fountain. Individual laminae do not stand out as sharply in section as do those previously described. However, on dip slopes of dissected hogbacks, both areal and sectional exposures may be observed. Individual laminae within a set thicken, thin, and in places wedge out completely. These are the exposures which most closely resemble those photographed by Knight as examples of "festoon cross-lamination."

An attempt was made to secure enough dip and strike readings on cross laminae to determine the direction of flow of the depositing currents. However, the attempt was abandoned when it became evident that few chance exposures could be relied upon for the data required. There are many exposures in which cross laminae can be observed dipping toward the axis of the channel in which they were deposited. There is no means of knowing the relationship of the direction of dip of these cross laminae to the direction of flow of the major currents within the channel.

No structures resembling "torrential cross bedding" were observed in any of the Fountain exposures in the Colorado Springs Quadrangle.

*Mud cracks.*—Mud crack structures were observed near the summit of the

[13] S. H. Knight, "The Fountain and Casper Formations of the Laramie Basin, A Study on Genesis of Sediments," *Univ. Wyoming Pub. in Sci., Geol.*, Vol. 1, No. 1 (1929), pp. 56–58.

main Fountain hogback in Little Bear Creek valley approximately 850 feet above the base of the formation. On a few bedding planes within a red medium-grained sandstone 15 feet thick there are low, narrow ridges of gray to white more coarsely grained sandstone forming polygonal patterns. There is considerable variation in the diameters of the polygons, ranging from 5 inches on one bedding plane to more than 18 inches on another. At only this one locality did the writer observe such structures in the Fountain of the Colorado Springs Quadrangle.

*Clastic dikes.*—Clastic dikes are not uncommon in the Fountain. Many are

FIG. 8.—Cross bedding of Knight's festoon type in coarse conglomeratic sandstones of Fountain. Exposure is at summit of principal Fountain hogback in valley of Little Bear Creek.

small, pentrating a very few inches into overlying or underlying formations, whereas others are 5–6 inches thick and one of these extends through a bed that is 5 feet thick. Large dikes were noted particularly in the upper Fountain in the Garden of the Gods (Fig. 2) and in the lower Fountain along Little Bear Creek. At the former locality it was possible to observe these structures in three dimensions.

At the exposure in the Garden of the Gods two beds of conglomeratic sandstone are separated by a 5-foot layer of dark maroon massive shaly sandstone which is firm near the base and much weathered at the top. Penetrating the maroon layer from bottom to top is a vertical tabular body of the same coarse-grained material as the overlying and underlying conglomeratic sandstone. The dike varies from 3 to 5 inches in thickness and can be followed for a distance of

6 or 7 feet in a S. 70° E. direction. Nearby are five smaller dikes also trending approximately S. 70° E. and two others trending almost at right angles to this direction.

All eight dikes widen considerably at their bases and join the underlying conglomeratic sand with no apparent break. At the contacts between the dikes and the overlying sandstone there is less widening of the dikes, and the conformity of contact is less evident. At exposures along little Bear Creek smaller dikes have obviously penetrated upward but failed to break through the top of the bed penetrated. These relationships indicate that the dike material was forced up from below. Dikes of this nature appear to be normal structures in formations like the Fountain. They were also observed by the writer in the Permo-Pennsylvanian redbeds at Texas Creek, Colorado, in the Arkansas Valley above the Royal Gorge.

At many contacts along which sandstone overlies shale, projections of bleached sand extend downward into the shale. Stratification across the sand projections suggests that they are the result of slow filling of fissures preceding deposition of the overlying sandstone of which they are seemingly a part. The irregular, apparently eroded top surface of the shale along these contacts supports this explanation of the origin of these small sand dikes.

Other original structures of sediments such as ripple, wave, frost, and raindrop marks were not observed in the Fountain formation.

### COLOR OF FOUNTAIN

*Distribution of color.*—Calculations based on measured sections indicate that more than 80 per cent of the total thickness of the Fountain is composed of beds that are definitely red in color. Variations from the predominant red color may be observed at many outcrops but distribution of non-redbeds within the formation as a whole is erratic. In the Manitou embayment non-redbeds are of consequence only in the basal 700 feet and in the upper 800 feet of the formation; in the remaining 2,900 feet colors other than red are almost entirely absent. Along Little Bear Creek and to the south non-redbeds are present at intervals throughout the total thickness of the formation.

*Nature of color variations.*—The use of the term "bleached" to describe parts of redbeds from which the color has presumably been removed is established in geologic literature and is so used in this paper. It should be noted, however, that the color change may involve actual removal of material in which case "leached" would be a more accurate term. In the Fountain, at least, some of the non-redbeds, particularly the thicker ones, may never have been red. To the writer's knowledge there is no way of proving that a discrete white, gray, or green bed, even though it lies between beds of brilliant red hue, was ever red.

Inasmuch as proof of bleaching of entire beds within the Fountain is not established at the present time, attention is directed to the small-scale examples where color change is more definite. Outstanding among these are the white, gray, or green bands extending from a fraction of an inch to several inches above

and/or below bedding surfaces. These bands are most obvious in the upper less conglomeratic Fountain sandstones but are also developed to some extent in the lower Fountain.

At several exposures on the Red Creek anticline these bands are sharply offset by small faults. Significantly there is no color change along the fault surface which must have offered some passage to groundwater in the past if not at present. At other exposures these bands are abruptly truncated by cross laminae or other channel-fill deposits. In many exposures the truncating sediments are more permeable than the sandstones that appear to have been bleached, yet the former show no evidence of loss of red color.

The color lines between red and non-red parts of non-conglomeratic sandstones are generally very sharp; in many exposures they are traceable across the surfaces of single grains. At shale-sand contacts color change, if present, is almost without exception in the sand; where the sandstone is the overlying bed of the two, projections of bleached sand may extend downward into the shale.

Many color contacts between red and non-red parts of the Fountain beds cut across laminations or follow an extremely irregular course across the exposed surfaces of massive thick-bedded units. Examples of these irregular and cross-cutting color lines are more abundant in beds of poorly sorted material than in the relatively well sorted sandstones; they are particularly abundant in the shaly zones.

In some of the dense limestones and fine-grained calcareous sandstones white spheres are found entirely surrounded by red rock from which they differ only in color. These spheres range in size from 1½ inches in diameter down to those barely visible to the naked eye. In some exposures these small white spheres are so abundant they give the rocks an evenly stippled appearance.

The only evidence that loss or red color from relatively unweathered beds is going on at the present time is in recently developed exposures of red poorly consolidated shaly sandstone where root systems of present day vegetation are uncovered. In these, individual roots are marked by white stringers and streaks extending down into the sandstone.

#### RELATIONSI IP OF FOUNTAIN TO UNDERLYING FORMATIONS

Throughout most of the Manitou embayment the Fountain rests conformably on the Glen Eyrie formation. In the southwestern part of the quadrangle the Fountain overlies older Paleozoic formations with angular unconformity or rests directly on eroded pre-Cambrian rocks.

Near the head of a small gully just south of the divide between Little Fountain and Little Bear Creeks (Fig. 3) eroded Manitou dolomite, dipping approximately 80° SE., is directly overlain by a Fountain sandstone dipping approximately 30° in the same direction. Farther south the angular nature of the unconformity is just as much in evidence, if less spectacularly so. Along Little Bear Creek basal Fountain is in contact with all three of the older Paleozoic formations that crop

out in the region, the Ordovician Manitou dolomite and Harding sandstone and the Mississippian Madison limestone. A short distance south of Little Bear Creek, Fountain rests on Pikes Peak granite and at one exposure, at least, Fountain directly overlies the rhyolite intrusives in the granite. Contact of Fountain with any one or several of these older formations may be seen at different places southward along the mountain front. Further evidence of the angular unconformity at the base of the Fountain has been demonstrated by Glockzin and Roy in the Red Creek area.[14]

FOUNTAIN-LYONS CONTACT

Most writers have accepted the 100–600 feet of red generally non-arkosic sandstone above the Fountian in the Colorado Springs Quadrangle as equivalent to the type Lyons, of questionable Permian age, in St. Vrains Canyon, Colorado where the Fountain and Lyons are separated by the Ingleside formation. However Lee[15] states that the Lyons of the type locality and the Ingleside wedge out toward the south and disappear north of Denver between Eldorado and Morrison, and that the Lyons of the Colorado Springs area is actually a part of the Fountain formation. He also states that the Ingleside at St. Vrains Canyon is unconformable with both the underlying Fountain and the overlying Lyons.

The writer visited the localities described and photographed by Lee in St. Vrains Canyon but was unable to find any evidence for unconformities at the top and base of the Ingleside. No features of the Ingleside were observed that are not duplicated by the Fountain in the Colorado Springs area. The Lyons of the type locality differs from the red sandstones overlying the Fountain in the Colorado Springs area primarily in degree of cementation; some of the sandstone being quarried at Lyons is almost quartzitic. At Lyons individual beds within a zone of cross bedding may be traced for distances of more than 100 feet along quarry walls without noticeable change in thickness. However, this uniformity and magnitude of cross bedding at the type locality is only slightly more spectacular than that exposed in red sandstone quarries above the Fountain in Red Rock Canyon in the southern part of the Manitou embayment.

The writer considers the red sandstone above the Fountain in the Colorado Springs Quadrangle to be equivalent to the Lyons because of (1) lithologic and structural similarities to the type Lyons, and (2) the uncertainty of the unconformable relationship at the base of the type Lyons.

In the southern part of the Manitou embayment the contact between Fountain and Lyons is gradational, but the transition zone of the Fountain is noncalcareous and does not include the upper limestone used for mapping in the southwestern part of the quadrangle. In Red Rock Canyon the gradation from Fountain to Lyons occurs over an interval of about 30 feet. Coarse-grained ar-

[14] A. R. Glockzin and C. J. Roy, "Structure of the Red Creek Area, Fremont County, Colorado," *Bull. Geol. Soc. America*, Vol. 57 (1945), p. 822.

[15] W. T. Lee, "Correlation of Geologic Formations between East Central Colorado, Central Wyoming, and Southern Montana," *U. S. Geol. Survey Prof. Paper 149* (1927), Pl. I and p. 32.

kosic Fountain sandstone with a few small pockets and lenses of medium-grained red sand is overlain successively by thin interbedded arkosic and non-arkosic red sandstones, very slightly conglomeratic red sandstone, cross-bedded non-arkosic red sandstone, interbedded red sandstone and thin coarse conglomerates, and finally the basal Lyons sandstone which is more than 200 feet thick at this locality.

For most of the distance from Fountain Creek to beyond the north edge of the embayment the Fountain is in fault contact with the Lyons or with Mesozoic formations.

In the southern part of the Colorado Springs Quadrangle the upper 100 feet of Fountain is highly calcareous and includes thin beds of non-arkosic sandstone much like the main sandstones of the Lyons. This transition zone is overlain by 80 feet of red, massive medium-grained non-arkosic sandstone which makes up the lowermost Lyons. Because this basal sandstone is not exposed over much of the area the "Contact" limestone in the upper part of the transition zone of the Fountain was used as the key bed for mapping purposes.

In the Colorado Springs Quadrangle the Lyons as a whole is readily separable from the Fountain despite the gradational contact between the two. The middle part of the Lyons is somewhat like the Fountain in that there are small conglomeratic and arkosic bodies. However cross bedding of the Lyons is on a much larger scale than most of that in the Fountain, and cut and fill structures are much less abundant. The sandstones of the upper Lyons are characterized by networks of resistant siliceous veinlets which stand out sharply from the weathered surfaces; these were not observed in any Fountain beds. In the southwestern part of the quadrangle the Lyons is almost identical in color to the Fountain. In the Manitou embayment, however, gray sandstones 100 feet and more thick are among the prominant hogback forming beds of the Lyons.

### SUBSURFACE DEVELOPMENT OF FOUNTAIN AND GLEN EYRIE FORMATIONS

The subsurface development of Pennsylvanian strata eastward from the areas of exposure is in part revealed by cuttings and a few cores from four wells. Two of these, one drilled by the Continental Oil Company and the other by the Colorado Petroleum, Inc., are located on the Red Creek anticline; the other two were drilled by the Continental north of Pueblo, Colorado (Fig. 1). The sections penetrated by these wells indicate that for a distance of about 18 miles eastward from the outcrop the Fountain thickens at a rate of slightly more than 100 feet per mile. For at least the same distance there are only minor lithologic changes; in the easternmost of the four wells the Fountain is composed predominantly of red coarse arkosic sediments.

Samples of a complete section of Fountain are available from the Continental Oil Company's State No. 1, drilled in the spring of 1946, and were examined by the writer. The well is located on the Red Creek anticline in the SE. $\frac{1}{4}$ of Sec. 4, T. 18 S., R. 67 W., Pueblo County, Colorado. It is approximately $\frac{1}{2}$ mile downdip

from the surface trace of the Fountain-Lyons contact. The total depth of the well is 1,938 feet in granite. No electric log was run and no oil showings were reported.

The hole was spudded in Lyons sandstone, and the first 250 feet of drilling was in that formation. The Fountain-granite contact is not less than 1,820 feet beneath the surface; there is no evidence for the presence of the Glen Eyrie or of any Lower Paleozoic formation. Thus the thickness of the Fountain in this well is approximately 1,570 feet, slightly thicker than the nearest measured section on the surface.

As would be expected the cuttings indicated that the lithologic character of the Fountain at this location is much the same as in the near-by surface exposures. Red coarse-grained arkosic sandstones and conglomerates, with thin beds of red silty and micaceous shales, and dense varicolored limestones constitute the entire Fountain section and appear identical with their counterparts at the surface.

The Colorado Petroleum, Inc., L. V. Hart No. 1, was drilled 4 miles northwest of the Continental's State No. 1, in Sec. 17, T. 17 S., R. 67 W., El Paso County, Colorado. The operators spudded in and drilled approximately 1,000 feet through coarse arkosic sediments that differed in no way from the Fountain as exposed at the surface. Although Fountain was logged to the total depth of 3,504 feet, it is the writer's belief that the base of the Fountain is not lower than 1,022 feet beneath the surface and that the hole was drilled in pre-Cambrian igneous rocks from slightly shallower than 1,090 feet to the total depth. Following is the evidence leading to this conclusion, part of which is based on the writer's examination of a cut of the samples from the well.

1. Between 1,022 feet and 1,070 feet the cuttings showed a quantity of dense to finely crystalline red-brown glauconitic dolomitic limestone very similar to much of the Ordovician Manitou formation as it occurs at the surface.

2. The cuttings below 1,070 feet, which were logged at the well as granite wash, are composed of quartz and feldspar as are most of the Fountain sandstones. However crystalline association of fresh feldspar, quartz, and biotite, an association rare in cuttings above 1,070 feet and in the Fountain at the surface, was of common occurrence.

3. Nine rock bits were used in drilling from the surface to 1,050 feet; 69 rock bits were used in drilling from 1,050 feet to 2,285 feet. Below 1,080 feet shreds of steel, apparently from the drill bit, are abundant in the cuttings.

4. The electric log shows marked increase in resistivity in the interval between 950 feet and 1,100 feet.

| *Depth in Feet* | *Normal Resistivity Curve Value in Ohm-Meters* | *Lateral Investigation Curve—Value in Ohm-Meters* |
|---|---|---|
| 0 to 950 | 10 to 60 | 10 to 60 |
| 950 to 1,050 | 40 to 150 | 30 to 100 |
| 1,050 to 1,090 | 250 to 750 | 500 to 1,250 |
| Below 1,090 | 500 to 2,250 | 1,000 to 20,000 (Values lower than 5,000 rare) |

Oil showings and oil stains in the cuttings were logged at various depths between 1,934 and 2,955 feet by the geologist on the well. Tests in open hole and through perforations indicated no possibilities of production. The samples had been washed before they were examined by the writer and no attempt will be made to explain these reported oil showings in what is, in this paper, considered to be the "basement complex."

The well was completed as an artesian water well through perforations in the interval 925–950 feet. In the summer of 1946, 6 months after completion, the well was flowing a very small stream, less than $\frac{1}{4}$ inch, of non-potable water.

In 1942 the Continental Oil Company drilled its Young No. 1 in sec. 11, T. 19 S., R. 65 W., Pueblo County, Colorado, to the depth of 6,112 feet. The location is 18 miles east of the nearest exposures of Fountain. Samples were examined by the Darby Petroleum Corporation and interpreted as follows.[16]

| *Depth* | *Formation* | *Thickness in Feet* |
|---|---|---|
| 2,085 | Top of Lyons sandstone | |
| 2,290 | Top of Fountain formation—coarse arkosic material with some fine red sandstone and dark red silty shale | |
| 5,710 | Top of Glen Eyrie formation. Mottled maroon and green arkosic shales | 30 |
| | Coarse arkosic sandstone with gray to black waxy hard shale in lower part | 50 |
| | Coal and carbonaceous shale | 10 |
| | Coarse white quartzitic sandstone | 30 |
| | Dense waxy gray-green shale | 5 |
| | White micaceous sandstone | 5 |
| | Biotitic black shale with two seams of hard coal | 20 |
| 5,860 | Top of Madison limestone (may also be Williams Canyon, Devonian, and Manitou present) | |
| 6,065 | In granite | |

The well was abandoned at 6,112 feet. To the writer's knowledge no oil showings were reported and no electric log was run. No fossils were mentioned by Koester in his communication.

In the latter part of 1945, the Continental Oil Company drilled Paige No. 1, 16 miles north of Pueblo and 15 miles east of the nearest Fountain outcrop on the Red Creek anticline. The well is in Sec. 6, T. 18 S., R. 67 W., Pueblo County, Colorado. The following brief summary of Paleozoic formations penetrated and the description of the Fountain are based on the writer's examination of cuttings and cores.

| *Depth in Feet* | *Formation* |
|---|---|
| 2,910 | Top of Lyons |
| 3,190–3,390 | Gap in samples |
| 3,390 | In Fountain |
| 6,605 | Top of Glen Eyrie? |
| 6,715 | Top of Madison limestone |
| 6,916 | Top of Manitou dolomite |
| 6,932 | Total depth—in dolomite |

[16] E. A. Koester, Darby Petroleum Corporation—written communication to C. J. Roy, Louisiana State University—December, 1942.

The total thickness of the Fountain in this well is more than 3,200 feet, as the Fountain-Lyons contact is within the 200-foot interval for which there were no samples. The top of the Glen Eyrie formation equivalent was determined at the depth at which brown and variegated green and red shales and siltstones become predominant over red coarsely arkosic sandstone. The depth of the first appearance of pink dense dolomitic limestone was picked as the top of the Madison. According to these figures the Glen Eyrie formation is 110 feet thick, 40 feet thinner than recognized in the Continental's Young No. 1, 7 miles south.

Although conglomeratic beds are difficult to recognize in well cuttings the Fountain section in this well is apparently less conglomeratic than in the surface exposures at the west. Fragments of feldspar and quartz up to 10 millimeters in diameter, suggestive of the poor sorting characteristic of the beds at the surface, are of common occurrence in the samples. However, abundant quartzite was not observed above 6,190 feet, 400 feet above the base of the Fountain. No significant amount of chert, the other principal constituent of conglomerates at the surface, was noted above the Madison.

Feldspar can be recognized in most of the coarse-grained sandstones although it is subordinate in amount to quartz. Under the microscope feldspar could not readily be identified in sandstones of grain size under 0.5 millimeter. Acid etching indicated that very little feldspar is present in these sandstones.

The calcareous nature of many of the sandstones in these redbeds which underlie several thousand feet of younger sediments is more evident than in the surface exposures. In general the amount of calcareous material varies with coarseness of grain. Calcareous sandstones are numerous, calcareous siltstones less so, and calcareous shales are rare.

A peculiar association was noted in some of the coarse-grained sandstones. Under the microscope grains of dark, in places red, silty shale could be recognized as constituents of uncrushed fragments of sandstone. In all such specimens the shale fragments were rounded and of about the same size as the quartz and feldspar grains making up the bulk of the sandstones.

Gray, green, and black shales are more abundant in the cuttings from this well than in the surface exposures. Below 6,605 feet, in what is considered to be the Glen Eyrie formation, cores of shale and silty shale show irregular green, brown, and red streaks that are entirely unrelated to bedding. The same irregularities of color distribution may be observed at the surface. None of the hard waxy black shale reported from the Glen Eyrie in the Continental's Young No. 1, was observed in the cuttings of this well.

Distribution of limestone within the section of this well does not correlate with that of the surface sections. Limestone fragments were not observed in the cuttings above 4,600 feet, at least 1,300 feet below the Fountain-Lyons contact. Below that depth thin, finely crystalline, varicolored limestones appear to be numerous.

The only fossils observed were in the interval between 6,560 and 6,595 feet.

They consisted of a few segments of crinoid stems, and three or four crushed and corroded ostracod valves. The latter are similar in outline to some of the ostracods from surface exposures of Glen Eyrie but preservation was too poor to allow definite identification.

The following additional well information is included in a dissertation by the writer, *Pennsylvanian Stratigraphy of the Colorado Springs Quadrangle, Colorado*, in the Louisiana State University Library: (1) descriptions of samples from the Continental Oil Company's State No. 1, and Paige No. 1, and from the Colorado Petroleum, Inc. Hart No. 1; (2) additional information on the latter well including copies of the report on testing, of the sample descriptions and geological report by the geologist on the well, of the electrical log, and of temperature data.

### AGE OF GLEN EYRIE AND FOUNTAIN FORMATIONS

The Glen Eyrie and Fountain have long been considered as lower Pennsylvanian formations without very definite paleontologic evidence.[17] However, the writer believes that the invertebrate fossils of the Glen Eyrie and Fountain indicate that the two formations are equivalent to, or perhaps younger than, some part of the Des Moines series of the Pennsylvanian section of Kansas.

### EVIDENCE OF GLEN EYRIE FAUNA

*Ostracods of the Glen Eyrie.*—The twelve species tentatively identified by the writer plus others not identified were checked by Mrs. E. H. Nadeau (Betty Kellett). Mrs. Nadeau is of the opinion that at least two, and possibly eight, species of the fauna are undescribed forms. Of the remaining, *Bairdia hoxbarensis* Harlton, *Geisina arcuata* (Bean), and *Kirkbya clarocarinata* Knight range from the Marmaton upward in the Mid-Continent section; *Glyptopleura spinosa* Harlton and *Healdia formosa* Harlton are known only in the Des Moines series; *Monoceratina ardmorensis* Harlton and *Amphissites wapanuckensis* Harlton (*Polytylites wapanuckensis* of Cooper, 1946) are limited to the Morrow and possibly the Lampasas series. The distribution of these seven species within the Mid-Continent Pennsylvanian section is shown in Table II.

In general this ostracod fauna is of a lower or middle Pennsylvanian type, probably not younger than Des Moines. However the fauna includes nearly as many undescribed species as known ones and presents some new associations of known species. These ostracods as well as the conodonts listed in the next paragraphs are to be figured and described in detail in the near future.

*Conodonts of Glen Eyrie.*—The Glen Eyrie conodont fauna consists of six species of four genera that are characteristic of the Pennsylvanian, and several species that are undescribed. The following have been identified by the writer, *Idiognathodus lobatus* Gunnell, *Idiognathodus* aff. *I. claviformis* Gunnell, *Streptо-*

[17] G. I. Finlay, "The Gleneyrie Formation and Its Bearing on the Age of the Fountain Formation in the Manitou Region, Colorado," *Jour. Geol.*, Vol. 15 (1907), pp. 586–89.

*gnathodus cancellosus* (Gunnell) Ellison, *Spathodus minutus* Ellison, *Cavusgnathus flexa* Ellison and *Cavusgnathus giganta* Gunnell. In the Mid-Continent Pennsylvanian section these six species are associated only within the Missouri series. In addition to the foregoing an undescribed species of *Streptognathodus* and a specimen questionably referred to *Polygnathodella* are present. The latter genus has not been reported in the upper Pennsylvanian.

A more detailed stratigraphic distribution of the six conodont species identified is presented in Table II. It is apparent that while the conodont fauna appear younger than that of the ostracods, four of the conodont species are known from Des Moines strata. Inasmuch as these six conodonts are rather long-range species the ostracods are probably more diagnostic. It is concluded that the Glen Eyrie is equivalent to some part of the Des Moines series of the Mid-Continent section, but that faunal evidence does not permit closer correlation.

TABLE II

RANGES WITHIN THE MID-CONTINENT PENNSYLVANIAN SECTION OF SPECIES IDENTIFIED IN THE GLEN EYRIE AND FOUNTAIN FORMATIONS

| SERIES | MORROW | LAMPASAS | DES MOINES | | MISSOURI | | | | | VIRGIL | | | PERMIAN SYSTEM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GROUP | Johns Valley and Wapanucka formations (Oklahoma) | Atoka formation (Oklahoma) | Cherokee shale | Marmaton | Bourbon | Bronson | Kansas City | Lansing | Pedee | Douglas | Shawnee | Wabaunsee | |
| OSTRACODS | | | | | | | | | | | | | |
| *Bairdia hoxbarensis* | | | | x | x | x | x | x | x | x | x | x | x |
| *Geisina arcuata* | | | | x | x | x | x | x | | | | | |
| *Monoceratina ardmorensis* | x | x-? | | | | | | | | | | | |
| *Healdia formosa* | | | x-? | x | | | | | | | | | |
| *Amphissites wapanuckensis* | x | | | | | | | | | | | | |
| *Kirkbya clarocarinata* | | | | x | x | x | x | x | | | | | |
| *Glyptopleura spinosa* | | | x-? | x | x | x | | | | | | | |
| CONODONTS | | | | | | | | | | | | | |
| *Idiognathodus lobatus* | | | | | | x | x | x | | | | | |
| *Idiognathodus* aff. *I. claviformis* | | | | x | x | x | x | | | | | | |
| *Streptognathodus cancellosus* | | | | x | x | x | x | x | | | | | |
| *Cavusgnathus flexa* | | | | | | x | x | x | x | x | x | x | x |
| *Cavusgnathus giganta* | | | x | x | x | x | x | x | x | x | x | x | x |
| *Spathodus minutus* | | | x | x | x | x | x | x | x | x | x | x | x |
| BRACHIOPODS | | | | | | | | | | | | | |
| *Derbya crassa* | | | x | x | x | x | x | x | x | x | x | x | x |
| *Dictyoclostus portlockianus* | | | x | x | x | x | x | x | | | | | |
| *Spirifer opimus* | | | x | | | | | | | | | | |
| *Spirifer rockymontanus* | | | x | | | | | | | | | | |

EVIDENCE OF "RED CREEK" LIMESTONE FAUNA OF FOUNTAIN

Of the fossils present in the "Red Creek" limestone only the brachiopods were studied by the writer. Most of these are poorly preserved and difficult to recover from the limestone but study of many specimens revealed four species that could be identified.

One of these brachiopods was identified as *Derbya crassa* (Meek and Hayden) which ranges through most of the Pennsylvanian. Several specimens of a medium sized productid-type brachiopod were referred to *Dictyoclostus portlockianus* (Norwood and Pratten) which ranges from the base of the Des Moines series nearly to the top of the Missouri series. This species is considered to be identical to *Productus inflatus* var. *coloradoensis* Girty which occurs in the Pennsylvanian Hermosa and Weber formations south and west of the Colorado Springs Quadrangle.[18]

Specimens of *Spirifer rockymontanus* Marcou and *Spirifer opimus* Hall (*S. boonensis* Swallow of Girty) are the most abundant of the brachiopods in the "Red Creek" fauna. Both of these species have been reported by Girty and others from many localities in the Hermosa and other Pennsylvanian formations in central and southwestern Colorado and appear to be two of the most abundant brachiopods in the Pennsylvanian redbeds of the Rocky Mountain region. They are considered to be indicative of Cherokee (lower Des Moines) age. However both are very diversified species; the number of varieties of each has in the past caused considerable controversy as to whether both, or either, are valid species. Representatives of each are widely spread geographically but, according to the literature, are not especially abundant in any area except the Rocky Mountains.

Table II shows that although the species represented in the Glen Eyrie and Fountain formations vary widely as to stratigraphic range the individual ranges tend to overlap and center near the Des Moines series of the Mid-Continent Pennsylvanian section.

GEOLOGIC HISTORY

Interpretations and conclusions concerning conditions prevailing in the Colorado Springs Quadrangle during, and to some extent before, Pennsylvanian time follow. They are based primarily on evidence presented thus far, but additional evidence that would not have been pertinent to preceding parts of this paper are introduced in subsequent paragraphs.

*Pennsylvanian formations in the Colorado Springs Quadrangle represent the landward parts of a deltaic mass deposited in a subsiding trough east of the highland from which the sediments were derived.*

That the Pennsylvanian formations in the Colorado Springs Quadrangle were deposited under marine or near sea-level conditions is made evident by the following facts.

[18] G. E. Condra and C. O. Dunbar, "Brachiopods of the Pennsylvanian System in Nebraska," *Nebraska Geol. Survey Bull.* 5, 2d Ser. (1932), p. 79.

1. There are at least three zones within the Glen Eyrie formation which contain marine or brackish-water faunas. The lowest of these is near the base of the formation, the highest near the top.

2. The fauna of the "Red Creek" limestone in the southwestern part of the quadrangle indicates that for a short period in early Fountain time marine conditions prevailed locally.

3. The limestone beds higher in the Fountain are of much greater areal extent than the individual beds of sandstone and conglomerate with which they are associated. This relatively great extent indicated pronounced change in environment of deposition from that in which the sandstones and conglomerates accumulated.

4. Ostracods in the "Contact" limestone at the top of the Fountain which in section appear identical with ostracods of the marine Glen Eyrie fauna are strong evidence that these limestones are also deposits of marine environment.

Inasmuch as individual zones throughout the total thickness of Pennsylvanian sediments include marine deposits, it follows that deposition of the entire thickness of sediments must have taken place near sea level. The non-fossiliferous but not necessarily non-marine portions of both the Glen Eyrie and Fountain formations may be either subaerial or subaqueous deposits. For example, the "veneer" conglomerates described from the lower part of the Fountain at the type locality are completely unlike the conglomerates of the filled channels. However they closely resemble the thin scattering of pebbles and cobbles that may be spread over both the tidal and shallow-water parts of an open, otherwise sandy, beach.

Aside from these "veneer" conglomerates the evidence indicates that nearly all the Fountain conglomerates are results of the action of currents that were alternately scouring and depositing. Imbricate structure, preferred orientation of fragments, and other features supposedly diagnostic of deposition in certain environments are completely absent from Fountain conglomerates. Predominance of certain rock and mineral types within the conglomerates is more indicative of conditions at the source from which they were derived than of environment of deposition.

In addition to fossil and lithologic evidence pointing to deltaic deposition, there is the evidence furnished by the chief characteristics of the Fountain sediments. The irregular bedding and other sedimentary structural features exhibited by the Fountain are much more characteristic of large present-day deltas than are the top-set, fore-set, bottom-set bed relationships so commonly shown in diagrams.[19] Irregular lenticular bedding, filled channels, and cross bedding are the normal results of meandering aggrading streams typical of deltaic plains. Lenticular bedding and cross bedding are of common occurrence in the upper deposits of the alluvial section of the Mississippi River. Dissected sand bars exhibit a

[19] R. J. Russell, H. V. Howe, *et al.*, "Lower Mississippi River Delta," *Louisiana Geol. Survey Bull.* 8 (1936), pp. 9, 72–80, 137–48.

pattern of cross bedding that duplicates that of the "festoon" type in all respects; furthermore gravels are associated with the cross-bedded sands where currents are scouring the basal graveliferous unit of the alluvial section.[20] Even during periods of relatively constant stage the channel and banks of the lower Mississippi River are subject to change. Sand bars are built, others are shifted or destroyed. The channel is deeply scoured at some places while similar deep scours are being filled at others. The recent history of the Lower Mississippi River alluvial plain and of the Mississippi delta has been one of constantly shifting stream courses.[21]

It is not necessary to appeal to sharply changing stream gradients and water volumes and sudden changes in the supply of sediment to account for the sedimentary structural features in the Fountain formation.

During mid-Pennsylvanian time the Manitou embayment is believed to have been a principal center of deltaic accumulation. The absence in the Fountain of this area of fossils and limestone beds and almost complete absence of calcareous sediments of any kind suggest that in this area the delta was being built outward and upward too rapidly during Fountain time to allow development of marine embayments. The thickness of Fountain measured through the type locality in the Manitou embayment is nearly three times as great as the maximum thickness of the formation in the southwestern part of the area studied. However the similarity of vertical distribution of conglomerates through the Manitou embayment and Little Bear Creek sections indicates that the latter section is complete as compared with the type section. Thus the Fountain in the southwestern part of the quadrangle represents delta flank accumulation and the limestones developed there were probably deposited in delta-flank depressions[22] some of which were open to the sea.

*In the Colorado Springs Quadrangle the eastern margin of the Paleozoic highland from which Fountain sediments were derived coincided closely with that of the present-day Front Range.*

The only known source for the rhyolite in the Fountain conglomerates of Little Bear Creek valley are the pre-Cambrain intrusive bodies which occur at the edge of the present day mountain mass along the granite-sediment contact. Inclusion of fragments of this rhyolite within Fountain conglomerates and overlap of exposed rhyolite by Fountain beds indicates that these intrusive bodies were a part of the eroded highland but were not high enough to escape burial under Fountain sediments. During Pennsylvanian time the eastern part of the Paleozoic highland must have barely included these rhyolite intrusives just as does the main mountain mass of the present-day Front Range.

Deeply weathered rhyolite underlying Manitou dolomite in the southernmost

[20] H. N. Fisk, "Geological Investigation of the Alluvial Valley of the Lower Mississippi River," *Mississippi River Commission* (1944), p. 18; Fig. 68; Pl. 33.

[21] H. N. Fisk, *op. cit.*, pp. 37, 49–51.

[22] R. J. Russell, H. V. Howe, *et al.*, *op. cit.*, pp. 7–9.

canyon tributary to Little Bear Creek and unconformities within the Paleozoic section are evidence that at least this part of the Front Range was a positive element as early as pre-Manitou time and throughout most of Paleozoic time.

The Manitou embayment is part of a structurally low region that was long a negative element in the generally positive highland. The Sawatch formation, the Manitou dolomite, and the Madison limestone are present in the embayment in their thickest development between Canon City and the Colorado-Wyoming state line, over much of which distance they are very thin or absent. Inasmuch as the top contact of each is an unconformable one it is apparent that these formations were more protected from erosion in the Manitou embayment than elsewhere along the mountain front. Unconformably overlying the Madison limestone in the embayment, and present nowhere else along the mountain front, is the Glen Eyrie formation at least part of which is marine. Overlying the Glen Eyrie is the thickest known section of the Fountain formation.

Thus the distribution of certain constituent rocks, the sources of which are known, in the Fountain conglomerates and the distribution and thickness of the Paleozoic formations in the Colorado Springs Quadrangle led to one conclusion. Within the quadrangle the eastern margin of the Paleozoic highland coincided closely with that of the present Front Range, even to the presence of a structurally low area at the location of the present Manitou embayment.

*The Paleozoic highland from which Fountain sediments were derived was subject to more humid conditions than prevail at present and was probably less rugged than the present-day Front Range.*

The major source of clastic material of the Fountain in the area studied was the Pikes Peak granite which is coarsely granular to coarsely porphyritic. The constituent minerals are in the following proportions by weight.[23]

| | *Percentage* |
|---|---|
| Quartz | 33.4 |
| Microcline | 53.2 |
| Oligoclase | 2.6 |
| Accessory minerals (primarily biotite, some hornblende, apatite, *etc.*) | 10.8 |

Microcline perthite is the dominant feldspar of the sandstones and conglomerate matrices of the Fountain but comprises less than 30 per cent of these sediments. Quartz makes up nearly all the remainder. The feldspar appears fresh in hand specimens but it should not be construed that the granite was simply disintegrated and the feldspar transported to its present position in the Fountain sediments. The drop in proportion of microcline to quartz in the sediments indicates that at least half of the original amount of feldspar was lost in weathering of the granite.

The significant feature of the coarse fraction of Fountain conglomerates is the predominance of quartz, quartzite, and chert fragments over those of feldspar or

[23] E. B. Mathews, "The Granitic Rocks of the Pikes Peak Quadrangle," *Jour. Geol.*, Vol. 8 (1900), p. 219.

of granite and other crystalline rocks. Inasmuch as the highland was primarily granitic the fact that substances less easily decomposed than granite are predominant in the conglomerates indicates that weathering conditions were those under which granite tends to decompose. At the present time mantle rock, where present, over most of the Front Range is composed primarily of feldspar-rich gruss and pebbles, cobbles, and boulders of granite.

A weathered zone approximately 90 feet thick and of lateritic character underlies the Fountain on Flagstaff Mountain near Boulder, Colorado, 75 miles north of the Colorado Springs Quadrangle. The top of this zone grades downward into friable rock which, in turn, grades into fresh Boulder Creek granite. Wahlstrom states that,[24] "recent weathering has not affected the thoroughly decomposed rocks in the pre-Fountain weathered zone." The writer knows of no large area in the Front Range where, under the present climate, such a lateritic zone has formed.

Studies and X-ray analyses summarized by Raymond[25] show that the pigment of red soils in warm moist regions is largely hematite. Chemical and geologic evidence is introduced to demonstrate that under surface or near-surface conditions limonite is not, by dehydration, altered to hematite which is also the dominant pigment of the redbeds, but to goethite which imparts a brown or gray-brown color. Therefore the red pigment in formations like the Fountain must be hematite crystallized from hydrous ferric oxides during the formation of red soils on the land area from which the sediments were derived. Raymond concludes that red color in sediments is not necessarily an indication of deposition under arid conditions but does indicate that the source area of the sediments was warm and humid.

Rock fragments of boulder size are present only locally in the Fountain, and boulder conglomerates are rare and locally concentrated near the base of the formation. The thick coarse conglomerates in the gully west of the Crystal Park Toll Road in the southern part of the Manitou embayment have no comparable counterparts in the type section of the formation less than a mile north. The writer believes that had the highlands of Fountain time been comparable in ruggedness and relief with the present Front Range much of the Fountain would be comparable in coarseness with the Quaternary gravels of the "mesas" that flank the Front Range. In the latter, boulders are relatively abundant over much larger areas than are the local boulder conglomerates of the Fountain.

*The region in which Fountain sediments accumulated was more humid than it is at present.*

Reference has been made to the evidence introduced by Raymond to the effect that red color in sediments is not necessarily an indication of deposition

[24] E. E. Wahlstrom, "Pre-Fountain Weathering on Flagstaff Mountain Near Boulder, Colorado," *Bull. Geol. Soc. America*, Vol. 57, No. 12 (1946), p. 1240. (Abstract of a paper presented before the Geological Society of America, December, 1946.)

[25] P. E. Raymond, "The Pigment in Black and Red Sediments," *Amer. Jour. Sci.*, Vol. 240, No. 9 (1942), pp. 663–69.

under arid conditions. Because hematite in red sediments is present as free particles of minute size and as stain on grain surfaces, both vulnerable to deflation and wind abrasion, Raymond[26] reasons that, of the various environments to which red sediments may be carried, it is in an arid region that red color is least likely to be preserved.

In the Fountain redbeds the truncating of bleached zones by channel fill deposits which show no loss of color is indisputable evidence that this particular bleaching occurred as a result of some agent which, at the time of deposition, was available to the zone now bleached. The fact that some of the truncating channel-fill sandstones and conglomerates are even more permeable than the bleached zones indicates that circulation of ground water was of limited importance in the bleaching process.

Keller [27] has presented analyses of iron contents of bleached and unbleached redbeds and results of laboratory experiments to show that bleaching of redbeds is accomplished by two steps. Ferric oxide is extremely stable and insoluble under normal surface and near-surface conditions and must be reduced to the ferrous state before becoming soluble in the weak groundwater acids. Thus Keller apparently includes an actual removal of material in the bleaching process. He adds that hydrogen sulphide, the active reducing agent of ferric oxide, in nature is derived (1) from sulphide waters from beneath the surface, (2) by sulphate-reducing bacteria, or (3) from decaying organic material.

The first two of these sources of hydrogen sulphide are not likely to be of importance in very recently deposited sediments. It is more reasonable to suppose that decaying organic material was incorporated in the sediments. The fact that bleached bands so commonly follow surfaces between depositional units of the Fountain is interpreted as evidence of the presence of vegetation on those surfaces. Had the organic material been carried in with the sediments the resulting color changes would be more uniform throughout the beds. Favorable climatic conditions, certainly not arid, were required in order that vegetation of any kind could gain hold on exposed surfaces of the rapidly accumulating Fountain sediments. The black shales in the Glen Eyrie, the fossil plants reported by Finlay[28] from that formation, and the black shales of the lower Fountain in Quarry Canyon support this interpretation.

## CONCLUSIONS

The Pennsylvanian formations of the Colorado Springs Quadrangle are believed to be the landward parts of deposits of successive deltas which had thei-

[26] P. E. Raymond, "The Significance of Red Color in Sediments," *Amer. Jour. Sci.*, Vol. 213 (1927), pp. 234–51.

[27] W. D. Keller, "Experimental Work on Red Bed Bleaching," *Amer. Jour. Sci.*, Vol. 218 (1929), pp. 65–70.

[28] G. I. Finlay, "The Gleneyrie Formation and Its Bearing on the Age of the Fountain Formation in the Manitou Region, Colorado," *Jour. Geol.*, Vol. 15 (1907), p. 588.

apexes in the Manitou region. For the most part the rate of accumulation of sediments exceeded that of submergence of the deltaic mass with the result that after Glen Eyrie time few marine or brackish-water deposits were incorporated in the great thickness of coarse sediments, and fossils are consequently rare. The kind of sediments supplied and the nearness of the source area are responsible for the red color and coarse texture of the Fountain.

The validity of these conclusions and the extent to which they may be applied beyond the limits of the Colorado Springs quadrangle will be determined by future work. More extensive investigations of the following are suggested: (1) the stratigraphic and geographic distribution of Fountain conglomerates, particularly any of especial significance such as the rhyolite-bearing conglomerates in the valley of Little Bear Creek; (2) the extent outside the Colorado Springs Quadrangle of parts of the Fountain formation, such as the limestones of this paper, which appear to have been deposited under marine conditions; (3) the exact nature of the pigment in the Fountain, including careful analysis for any agent or material that may have had direct or indirect effect on the color; (4) the possibilities of additional faunal evidence as to the age of the Fountain and the environment or environments in which it was deposited.

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# PHYSICAL AND CHEMICAL PROPERTIES OF ELLENBURGER ROCKS, LLANO COUNTY, TEXAS[1]

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## ABSTRACT

Physical and chemical data are recorded for 75 samples from a stratigraphic section of the Ellenburger group on Riley Mountain, Llano County, Texas. The division of samples is as follows: limestone, 29; dolomite, 42; mixed rocks, 4; a cherty limestone, a dolomitic limestone, and two calcitic dolomite samples. The limestone has a dense to sublithographic texture with pellet and breccia structures as variations. The average insoluble content of the limestone is 2.4 per cent; the minimum calcite content, about 94 per cent; and the maximum calculated dolomite content, about 3 per cent. The average grain density of 16 samples is 2.705; the average porosity of 12 samples is 0.5 per cent.

Samples of the dolomite exhibit a range in texture and are classified in four groups: (1) microgranular and very fine-grained; (2) fine-grained; (3) medium-grained; and (4) coarse-grained. Physical and chemical properties are more variable than those of the limestone samples, with ranges as follows: grain density, 2.811 to 2.848; porosity, 1.1 to 12.6 per cent; insoluble content, 0.2 to 10.2 per cent; calculated calcite content, 2.7 to 27.2 per cent; and calculated dolomite content, 70.0 to 94.7 per cent.

Detrital minerals in the insoluble residues from the limestone and dolomite samples are quartz, feldspar, leucoxene, magnetite-ilmenite, tourmaline, zircon, muscovite, garnet, and apatite. Authigenic minerals include chert, quartz, feldspar, clay minerals, glauconite, and pyrite. Chert is the chief constituent of the residues, and varieties are dense or cryptocrystalline, fine to coarsely granular, and fibrous chalcedonic. The dense and coarse-grained cherts are complementary, one to the other, in their distribution. The chert, particularly of the dolomite, commonly is dolomoldic, as are also granular kaolin and glauconite. Siliceous oölites and fragments of siliceous spicules occur in a few residues.

In appearance and in bulk composition the limestone samples are remarkably uniform throughout the stratigraphic section. The dolomitic limestone and the calcitic dolomite samples come from a zone which marks the transition from the dolomitic to the calcitic facies of the Staendebach member of the Tanyard formation. The coarse-grained dolomite is restricted to the lower part of the Tanyard, and the microgranular and very fine-grained dolomite is limited to the Gorman and Honeycut formations. The residues from the Tanyard formation are characterized by dense chert; whereas the residues from the Gorman and Honeycut contain abundant detrital material, principally quartz and feldspar, in addition to chert.

Five detailed chemical analyses of the Ellenburger limestone and dolomite are given, and a method for determining the approximate composition of samples based on determinations of grain density and insoluble content is described. The data are presented in tables and graphically.

## INTRODUCTION

The purpose of this investigation is to determine the physical and chemical properties of samples of limestone and dolomite in a stratigraphic sequence. The properties determined are grain size or texture, grain density, bulk density, porosity, and mineralogical and chemical composition. The relationships between the physical and chemical properties are considered, and the variations of the properties with stratigraphic position are discussed. Basic data of this kind are scattered throughout geologic publications, but systematic studies of groups of related samples are strikingly few. The writers hope that the methods and results presented at this time will interest others in similar investigations. Precise chemi-

[1] Manuscript received, July 31, 1947. Published with the permission of the director of the Bureau of Economic Geology, The University of Texas.

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cal results are needed as well as additional methods for the rapid appraisal of the composition of carbonate rocks. Petrographic methods applied to the study of insoluble residues promise useful returns. It is hoped that the data on bulk density will be of use to seismologists. and that similar studies will be undertaken on cores.

The present investigation is based on a stratigraphic section measured during a co-operative project on the Ellenburger group in central Texas by the Geological Survey of the United States Department of the Interior and the Bureau of Economic Geology of The University of Texas,[4] and grateful acknowledgment is made to the contributions and co-operation of Preston E. Cloud, Jr., of the United States Geological Survey and Virgil E. Barnes of the Bureau of Economic Geology. Robert L. Manly, Jr., and Kenneth R. Johnson assisted in the sampling. The laboratory studies were made at the Agricultural and Mechanical College of Texas. Special thanks are due to Clay L. Seward who gave valuable assistance in the laboratory work. The final manuscript and photomicrographs were prepared in the Bureau of Economic Geology, The University of Texas. V. E. Barnes read the manuscript, and his criticism and many helpful suggestions are acknowledged with appreciation.

## ELLENBURGER GROUP IN LLANO UPLIFT

The Ellenburger limestone as defined by Paige[5] is comprised of a series of limestone and dolomite rocks in the Ellenburger Hills of southeastern San Saba County, Texas. According to Paige, the Ellenburger is underlain by the Wilberns formation (Cambrian) and generally overlain by an unnamed thin conglomeratic limestone which is in turn overlain by the Marble Falls limestone (Pennsylvanian). By definition and common usage the "Ellenburger limestone" had come to mean all the Upper Cambrian and Lower Ordovician rocks between these rather general limits. Subsequent work by Dake and Bridge,[6] indicated the need for revision of the term "Ellenburger limestone." In 1943, geologists of the Texas Bureau of Economic Geology and the United States Geological Survey joined in a co-operative project to investigate the Ellenburger in central Texas.

In the preliminary report by Cloud, Barnes, and Bridge,[7] the "Ellenburger limestone" is revised to group status, restricted to rocks of Lower Ordovician age,

[4] P. E. Cloud, Jr., V. E. Barnes, and Josiah Bridge, "Stratigraphy of the Ellenburger Group in Central Texas—A Progress Report," *Univ. Texas Pub. 4301* (1945), pp. 133–77.
P. E. Cloud, Jr., and V. E. Barnes, "The Ellenburger Group of Central Texas," *Univ. Texas Pub. 4621*, in press.

[5] Sidney Paige, "Mineral Resources of the Llano-Burnet Region, Texas," *U. S. Geol. Survey Bull. 450* (1911), p. 24.
———, "Description of the Llano and Burnet Quadrangles," *U. S. Geol. Survey Geol. Atlas, Llano-Burnet Folio 183* (1912).

[6] C. L. Dake and Josiah Bridge, "Faunal Correlation of the Ellenburger Limestone of Texas," *Bull. Geol. Soc. America*, Vol. 43 (1932), pp. 725–41.

[7] *Op. cit.*, pp. 139–47.

and divided into three formations, from oldest to youngest, the Tanyard, the Gorman, and the Honeycut. These formations are essentially equivalent to the Gasconade, Roubidoux, and Jefferson City formations of Missouri, and to the McKenzie Hill, Cool Creek, and Kindblade formations of Oklahoma. The lower contact of the Ellenburger is placed at the Cambrian-Ordovician boundary, because a local and possibly wide disconformity is indicated in the eastern part of the Llano uplift by a sharp faunal break. The Upper Cambrian formations below this break are generally glauconitic; whereas the overlying Ordovician rocks are essentially non-glauconitic. There are also marked differences in texture and color of the rocks below and above the boundary.

The predominating rocks of the Ellenburger are limestone and dolomite. The limestone is chiefly sublithographic, pearl gray to woodash gray, varying to brownish grays and light browns. Pellet limestone occurs locally throughout the Llano uplift. The dolomite ranges in texture from microgranular to coarse-grained and shows a great diversity in color, with pink, rose, beige, light gray, yellowish gray, purplish gray, and light brown predominating. The brighter-colored microgranular dolomite of the Gorman and Honeycut formations shows greater lateral persistence than the light-colored, coarser-grained dolomite of the Tanyard formation, which commonly grades laterally to limestone.

The maximum known thickness of the Ellenburger in outcrops in the Llano uplift is approximately 1,820 feet in the vicinity of Johnson City, Blanco County. North and west of Johnson City the group is thinned by truncation of the upper beds, so that is is slightly over 800 feet thick in McCulloch County. The Tanyard formation ranges in thickness from 658 feet in the eastern part of the Llano uplift to approximately 500 feet in the western part. It is divided into the Threadgill and Staendeback members. The Threadgill consists of medium- to coarse-grained, commonly vuggy dolomite, ordinarily a shade of light gray, and sublithographic, pearl-gray to woodash-gray limestone. The Staendeback member consists of similar limestone and fine- to medium-grained dolomite.

The Gorman formation has a maximum thickness of 498 feet. It is marked by the first appearance in significant quantities of microgranular dolomite in the Paleozoic sequence in central Texas. The lower 215 feet of the Gorman is predominantly varicolored shades of yellow, pink, and brown, microgranular to very fine-grained dolomite. The upper part is predominantly sublithographic thick- to thin-bedded limestone with locally interbedded microgranular to fine-grained dolomite. The limestone is woodash gray to brownish gray. A sequence of pure, exceptionally thick-bedded limestone occurs in the upper 40–60 feet of the Gorman formation.

Because of post-Ellenburger truncation, the Honeycut formation ranges in thickness from 678 feet in the southeastern part of the Llano uplift to a feather edge, disappearing entirely in the western part of the uplift. The rock types resemble those of the Gorman formation. The microgranular dolomite generally is duller in color than that of the Gorman, and the limestone and the dolomite are

TABLE I

ELLENBURGER GROUP AND ASSOCIATED FORMATIONS IN CENTRAL TEXAS

| *Age* | *Group and Formation* | *Member* | *Character* |
|---|---|---|---|
| Cretaceous | Travis Peak | Hensell sand | Red or yellow sand |
| | | Cow Creek limestone | Sandy limestone and shale |
| Pennsylvanian | Marble Falls | | Limestone |
| Mississippian | Barnett | | Shale |
| | Chappel | | Crinoidal limestone |
| | Ives | | Chert breccia |
| Devonian | Zesch | | Siliceous limestone |
| | Bear Spring | | Cherty limestone |
| | Stribling | | Cherty limestone |
| | Pillar Bluff | | Limestone |
| Lower Ordovician | Ellenburger group: Honeycut | | Microgranular to fine-grained dolomite and sublithographic limestone |
| | Ellenburger group: Gorman | | Microgranular to fine-grained dolomite and sublithographic limestone |
| | Ellenburger group: Tanyard | Staendebach | Fine- to coarse-grained dolomite and sublithographic limestone |
| | | Threadgill | Fine- to coarse-grained dolomite and sublithographic limestone |
| Upper Cambrian | Wilberns | Pedernales dolomite and San Saba limestone | Dolomite and limestone |

more thinly interbedded than in the Gorman. The basal beds of the Honeycut formation commonly are arenaceous.

The Ellenburger group is underlain by Upper Cambrian rocks including the Pedernales dolomite and the San Saba limestone members of the Wilberns formation. Because of pre-Devonian and later truncations the Ellenburger is overlain uncomformably by the formations shown in Table I with range in age from Devonian to Cretaceous. The Upper Cambrian formations of the Llano uplift are discussed in a recent paper by Bridge, Barnes, and Cloud,[8] and the Devonian rocks in a paper by Barnes, Cloud, and Warren.[9]

[8] Josiah Bridge, V. E. Barnes, and P. E. Cloud, Jr., "Stratigraphy of the Upper Cambrian, Llano Uplift, Texas," *Bull. Geol. Soc. America*, Vol. 58 (1947), pp. 109–24.

[9] V. E. Barnes, P. E. Cloud, Jr., and L. E. Warren, "Devonian Rocks of Central Texas," *Bull. Geol. Soc. America*, Vol. 58 (1947), pp. 125–40.

The life and probable environment of the early Ordovician sea in central Texas have been discussed by Cloud and Barnes.[10] They point out that the conditions of origin and deposition of the Ellenburger sediments may have been similar to present conditions in the Bahama Banks region. A more detailed discussion of the lithology, variations in composition, and probable conditions of deposition of the Ellenburger sediments is contained in the forthcoming publication by these writers.[11]

## RILEY MOUNTAIN SECTION

The Riley Mountain section sampled for this investigation is approximately 10 miles southeast of the town of Llano and is within easy access of the road from Llano to Click (Figs. 1 and 2). The section is a composite of the Moore Hollow and the Warren Springs sections which were measured and described in detail by

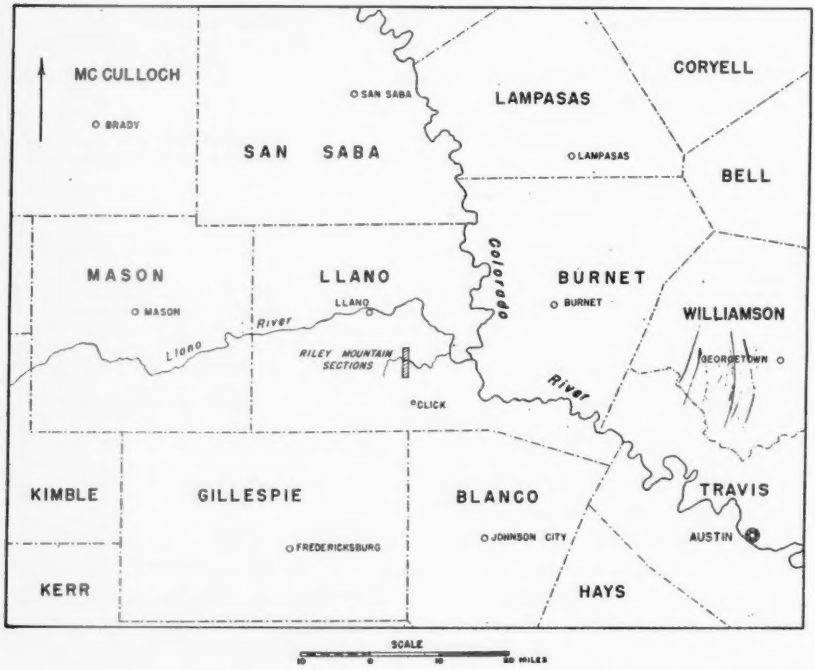



FIG. 1.—Index map showing location of Riley Mountain sections of Ellenburger group, Llano County, Texas.

[10] P. E. Cloud, Jr., and V. E. Barnes, "The Life and Environment of the Early Ordovician Sea in Central Texas," *National Research Council, Report of the Committee on Marine Ecology as Related to Paleontology, 1945–1946*, No. 6 (1946), pp. 87–101.

[11] Cloud and Barnes, *op. cit.*, in press.

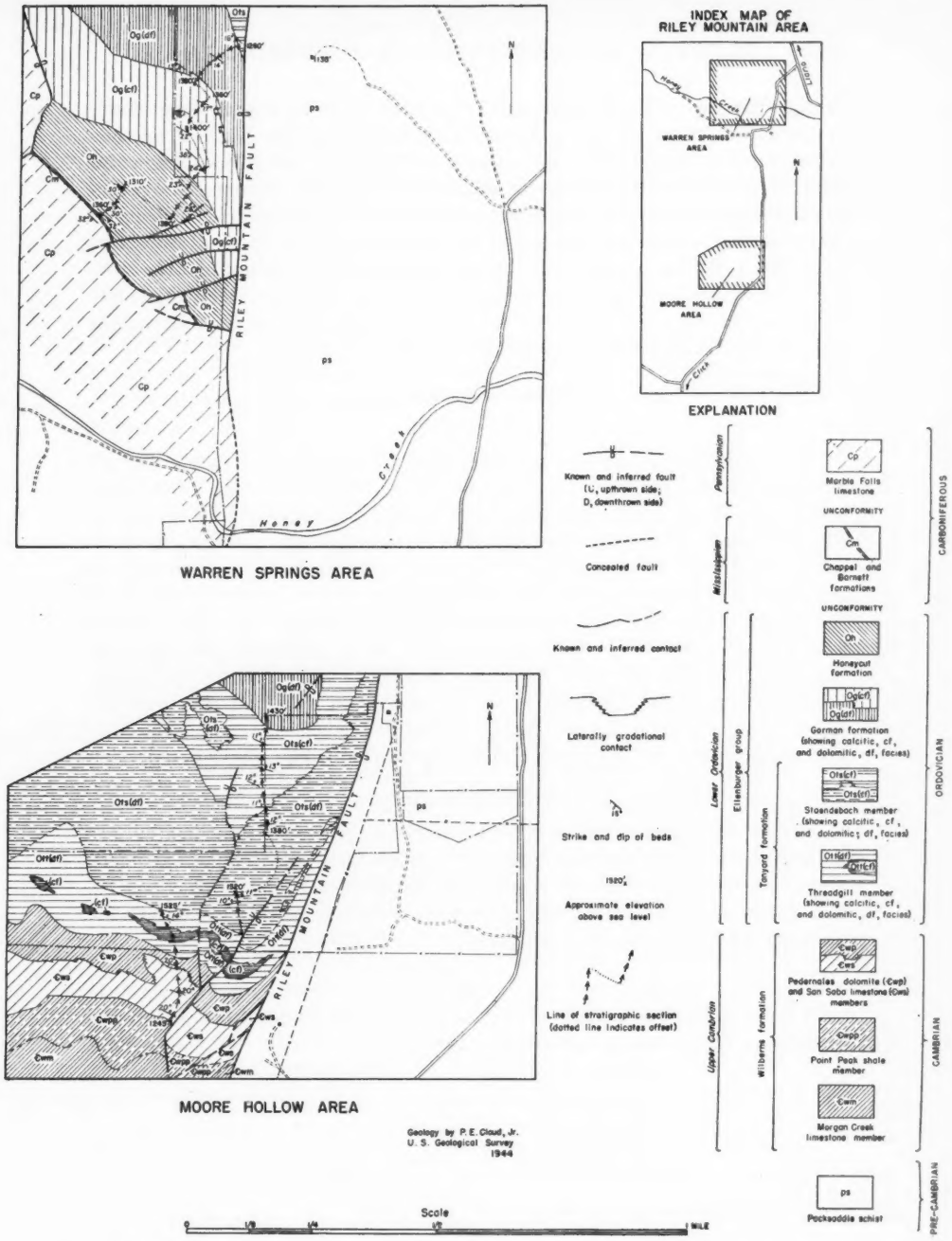



FIG. 2.—Geologic maps of Moore Hollow and Warren Springs areas, Llano County, Texas, showing line of stratigraphic section sampled. (Adapted from Plate X, Cloud and Barnes, "The Ellenburger Group of Central Texas," *Univ. Tex. Pub. 4621*, in press.)

Cloud.[12] The two sections are separated by Honey Creek (Fig. 2). The Moore Hollow section starts 332 feet below the Cambrian-Ordovician contact and ends 30 feet above the Tanyard-Gorman contact. A total of 965 feet of Ellenburger and Upper Cambrian strata are represented in the section. The Warren Springs section starts at the Tanyard-Gorman contact and ends at the Ordovician-Pennsylvanian contact. It includes 909 feet of the Ellenburger. The Tanyard formation in the Moore Hollow section (Fig. 7) is 602 feet thick. The Gorman and the Honeycut formations in the Warren Springs section (Fig. 8) are 456 feet and 453 feet thick, respectively, giving a total thickness of 1,511 feet for the Ellenburger group in the Riley Mountain stratigraphic section.

## METHODS AND TECHNIQUES

### FIELD SAMPLING

Spot samples were taken of the predominating rock types in each of Cloud's lithologic units in the Moore Hollow and Warren Springs sections. An 8-pound sledge hammer was used to break back into the bed rock to obtain as fresh a specimen as possible. In general, thin intervals were sampled once, and thick intervals one or more times. In measuring the sections Cloud marked 5-foot intervals on the bed rock in yellow paint and also indicated each 50-foot interval in feet above the base of the section. The marked intervals along the line of section together with Cloud's detailed lithologic descriptions greatly facilitated the sampling. Sample No. 1 is 313 feet above the base of the Moore Hollow section and 19 feet below the Cambrian-Ordovician boundary as mapped by Cloud. The points of sampling are marked in the field by black paint on the bed rock and are shown on the columnar sections of Figures 6 and 7 constructed from Cloud's descriptions.

### DESCRIPTION OF SAMPLES

A brief description of the samples was made at the time of sampling. Later, a more detailed description was made in the laboratory, with a binocular microscope. For consistency the terminology of Cloud, Barnes, and Bridge[13] was followed as closely as possible. Usage of the color terms was checked by consultation and comparison with Cloud and Barnes.

### TEXTURE

The following scale of grain-size limits as set up by Cloud and Barnes was used to differentiate the following textural varieties.

| *Textural Variety* | *Limits of Grain Size (Millimeters)* |
|---|---|
| Microgranular | Less than 0.05 |
| Very fine-grained | 0.05–0.2 |
| Fine-grained | 0.2 –0.6 |
| Medium-grained | 0.6 –1.2 |
| Coarse-grained | Greater than 1.2 |

[12] Cloud and Barnes, *op. cit.*, in press.

[13] *Op. cit.*, pp. 134–37.

Grain sizes were measured in reflected light with the use of the petrographic microscope. In the finer-grained rocks, reflections from cleavage faces were used in making measurements. In coarser-grained rocks, it was found that the individual grains were more readily recognized by staining the surface with ordinary ink diluted slightly with water. The grain sizes measured in this manner are only approximations, but the determinations permit relative grading so that a textural series of the samples from the finest to the coarsest can be set up.

### DENSITY

Density is the relationship between the mass and volume of a substance, and in the c. g. s. system is properly expressed in grams per milliliter (gm./ml.). Commonly, density is given in grams per cubic centimeter (gm./cm.$^3$). Density is conveniently determined by obtaining the weight of water displaced by the sample. The ratio of the weight of a substance to the weight of an equal volume of water is widely used as the "specific gravity" of the substance. For accurate work the "specific gravity" of a substance is of little value unless the temperature of the reference water is stated. Because the "specific gravity" value for a substance will vary with the temperature of the water, it is sound practice to calculate the "specific gravity" to 4°C. ($t°/4°$). This expression gives the "specific gravity" of a substance at some temperature ($t°$), usually room temperature, referred to water at 4°C. The "specific gravity" of a substance referred to water at 4°C. is essentially equivalent numerically to the density of the substance in the c.g.s. units (gm./ml.) and is so used in this paper in preference to the loosely used and less desirable term "specific gravity."

In the present investigation all determinations of grain density were made with the fused-silica pycnometer designed and described by Ellsworth.[14] This constant-volume pycnometer permits vigorous boiling of the water for expulsion of air trapped in the sample. A single weighing permits calculation of the grain density. The temperature of the water in the pycnometer is determined to 0.1°C. immediately after the weighing.

To check the calibration of the fused-silica pycnometer, tests were made on rock crystal quartz and clear calcite of optical quality. The "specific gravity" of quartz determined in water (24°C.) was found to be 2.657. The density (24°/4°C.) is 2.648. Sosman[15] states that "the density of all the clear transparent quartz which has been carefully examined lies within the limits 2.648 and 2.650 at room temperature." He gives a value of 2.651 as the density of low-quartz at 0°C. and one atmosphere. Recently published tables[16] give a density, at "room temperature" and one atmosphere, of 2.654 for quartz. It is not stated how this result was

[14] H. V. Ellsworth, "A Simple and Accurate Constant-Volume Pycnometer for Specific Gravity Determinations," *Min. Mag.*, London, Vol. 21 (1928), pp. 431–36.

[15] R. B. Sosman, "The Properties of Silica," *Amer. Chem. Soc. Monograph Ser. 37*, p. 289. Chemical Catalog Company, Inc., New York (1927).

[16] Francis Birch *et al.*, "Handbook of Physical Constants," *Geol. Soc. America Spec. Paper 36* (1942), p. 12.

obtained; therefore, Sosman's density of 2.649±.002 for clear transparent quartz at 20°C. is accepted here.

The density of clear transparent calcite was determined with the fused-silica pycnometer to be D 25.2°/4°, 2.709. This value is favorably comparable with results of different investigators:

DENSITY OF CALCITE AT 18°C.[17]

| *Density* | *Authority* |
|---|---|
| 2.7102±0.0004 | Defoe and Compton, *Phys. Rev.* 25, 618 (1925) |
| 2.71026 | Bearden, *Phys. Rev.* 38, 1939 (1931) |
| 2.71003 | Tu, *Phys. Rev.* 40, 662 (1932) |

The reproducibility of results obtained with the fused-silica pycnometer is shown in Table II. The greatest difference is 0.003 for sample No. 189.

TABLE II

DENSITY OF ELLENBURGER SAMPLES OBTAINED WITH FUSED-SILICA PYCNOMETER

| *Sample No.* | | *t°* | *D, t°/4°C.* |
|---|---|---|---|
| 3 | (a) | 23.7 | 2.846 |
| | (b) | 24.3 | 2.846 |
| 27 | (a) | 25.3 | 2.709 |
| | (b) | 27.5 | 2.710 |
| 67 | (a) | 24.8 | 2.699 |
| | (b) | 27.8 | 2.700 |
| 185 | (a) | 24.2 | 2.769 |
| | (b) | 24.5 | 2.767 |
| 189 | (a) | 23.2 | 2.799 |
| | (b) | 26.0 | 2.796 |
| 222 | (a) | 21.8 | 2.683 |
| | (b) | 24.9 | 2.683 |
| 241 | (a) | 24.8 | 2.763 |
| | (b) | 24.4 | 2.765 |

POROSITY AND BULK DENSITY

*Total porosity.*—Porosity is the volume of pore space compared with the total volume of the rock. Total porosity is given in the following equation.

$$(1) \qquad \frac{\text{Void}}{\text{Total volume}} \times 100 = (\%)\ \text{Porosity}$$

The relationship between grain density ($D_g$), bulk (apparent) density ($D_b$), and total porosity ($P_t$) of rock follows.

[17] A. H. Compton and S. K. Allison, "X-Rays in Theory and Experiment," p. 677. D. Van Nostrand Company, Inc., New York (1935).

$$(2) \qquad \frac{D_g - D_b}{D_g} \times 100 = P_t\ (\%)$$

In this equation the bulk or apparent density is the weight in grams of the dry rock divided by the total volume in milliliters or cubic centimeters. Total porosity, then, is easily calculated if grain and bulk densities are available. For determination of bulk density the volume of the dry specimen is obtained by displacement. The media that have been used for displacement measurements are mercury, water, and sand. In this study water was used.

If water is used as the displaced medium for determination of the volume of a porous rock, an impermeable coating must be applied to prevent the water from entering the pore space. Paraffine[18] has been used for this purpose, and properly handled is a satisfactory coating, but a correction must be applied for the weight and volume of the paraffine. Brankstone, Gealy, and Smith[19] recommend celluloid lacquers in place of paraffine. They found that for small specimens the weight of the celluloid coating could be kept below 0.02 gm., and they neglected the weight and volume of the coating in their calculations. In the present study larger specimens weighing from 50 to 100 grams were used to insure representative samples of the limestone and dolomite. For samples of this size it was found that the weight and volume of the cellulose acetate could not be neglected, and no advantage over the paraffine method results.

Specimens were dried at temperatures of 110°C. to 120°C. for periods of from 24 to 48 hours and cooled in a desiccator before being weighed and dipped in either paraffine or cellulose acetate. Weighings were made on an analytical balance, and in addition to usual bouyancy corrections, corrections also were applied for the weight of the fine silk thread used to suspend the specimen, and the weight and volume of the paraffine or cellulose acetate. The densities of these coating media were determined as follows: paraffine, 0.87; cellulose acetate, 1.20. The bulk density determinations were made at room temperature of 25°C. All determinations were recalculated and referred to water at 4°C.; hence are comparable in this respect to the grain densities.

Although bulk density figures are given to the third decimal place, these determinations are not considered to be as accurate as the grain density values obtained with the fused-silica pycnometer. Comparative figures for bulk density for 12 samples by the paraffine and cellulose acetate methods are given in Table III. These suggest that the paraffine method gives somewhat lower values. The maximum observed difference is 0.012 for sample No. 63 for which bulk densities of 2.729 and 2.741 were found by the paraffine and celluloid coating methods, respectively. The figures reported for bulk density are considered to have an accuracy of $\pm .01$, and on the whole probably fall well within this limit.

[18] A. F. Melcher, "Determination of Pore Space of Oil and Gas Sands," *Trans. Amer. Inst. Min Met. Eng.*, Vol. 65 (1921), pp. 469–97.

[19] H. R. Brankstone, W. G. Gealy, and W. O. Smith, "Improved Technique for Determination of Densities and Porosities," *Bull. Amer. Assoc. Petr. Geol.*, Vol. 16 (1932), pp. 915–23.

*Effective porosity.*—The effective porosity of a rock may be defined as the percentage of pore space of the total volume that will permit transmission of fluids or gases. Effective porosity does not include the volume of the isolated pore space—that is, the pore space completely walled off from the outside. Effective porosity is given in the following equation:

$$P_e(\%) = 100 \times \frac{V_b - V_s}{V_b}$$

In this equation $P_t$ is the effective porosity expressed in per cent of total volume, $V_b$ is bulk or total volume, and $V_s$ is the summation of the volume of the individual grains and the volume of the isolated pore space. Effective porosity is more

TABLE III

BULK (APPARENT) DENSITY OF ELLENBURGER SAMPLES BY PARAFFINE AND CELLULOID COATING METHODS

| *Sample No.* | $D_b$ (25°/4°C.) | | *Difference* |
|---|---|---|---|
| | *(A) Paraffine* | *(B) Celluloid* | *(A−B)* |
| 6 | 2.764 | 2.766 | −.002 |
| 13 | 2.746 | 2.749 | −.003 |
| 31 | 2.750 | 2.760 | −.010 |
| 44 | 2.748 | 2.755 | −.007 |
| 51 | 2.789 | 2.784 | +.005 |
| 52 | 2.769 | 2.779 | −.010 |
| 56 | 2.635 | 2.639 | −.004 |
| 61 | 2.706 | 2.715 | −.009 |
| 63 | 2.729 | 2.741 | −.012 |
| 69 | 2.775 | 2.775 | — |
| 72 | 2.553 | 2.550 | +.003 |
| 74 | 2.642 | 2.651 | −.009 |

closely related than is total porosity to the property of permeability. Where permeability measures the capacity of a medium to transmit fluids or gases, effective porosity measures the volume of the passageways involved in this transmission.

The Stevens[20] "gas-expansion type" porosimeter was used on a series of six samples of Ellenburger limestone and dolomite (Table IV). For these determinations cores approximately ½ inch in diameter and slightly less than 1 inch in length were cut. Sample No. 72, a microgranular dolomite with a total porosity of 10 per cent, has an effective porosity of 9 per cent. The effective porosity of each of the other five samples is small. Because of the small total porosity of the great majority of the samples and because of the time required to cut and prepare cores for the porosimeter, effective porosity is not considered a significant property in the present investigation. The small size of the core, limited by the size of the expansion chamber of the porosimeter, is another unfavorable factor. The average volume of these cores is less than one-fifth of the average volume of the

[20] A. B. Stevens, "A New Device for Determining Porosity by the Gas-Expansion Method," *Petrol. Tech., Amer. Inst. Min. Met. Eng. Tech. Pub. 1061* (1939), pp. 1–5.

fragments used in determining total porosity, and hence the cores probably are less representative of the rock samples.

### PERMEABILITY

Permeability is that property of a porous medium which determines the ease with which a fluid can migrate or pass through the medium. Although fundamentally dependent on porosity, permeability depends on connected pore space (effective porosity) and also to a very pronounced degree on the size of the openings. It is well known that clays and shales, although they may possess a large amount of pore space, may be essentially impermeable because of the fineness of

TABLE IV

EFFECTIVE POROSITY OF ELLENBURGER SAMPLES DETERMINED WITH STEVENS POROSIMETER

| *Sample No.* | *Rock Type* | *Per Cent Effective Porosity* | *Per Cent Total Porosity* | |
|---|---|---|---|---|
| | | | *Core*[a] | *Fragment* |
| 6 | Fine-grained dolomite | 1.3 | 4.5 | 7.1 |
| 13 | Fine-grained calcitic dolomite | 0.6 | 1.9 | 2.3 |
| 51 | Microgranular dolomite | 2.1[b] | 1.6 | 1.4 |
| 72 | Microgranular dolomite | 9.2 | 10.1 | 10.0 |
| 77 | Sublithographic limestone | 0.0 | 1.3 | 0.7 |
| 78 | Fine-grained dolomite | 2.1 | 4.0 | 3.3 |

[a] Cores are same as used for effective porosity.
[b] Probably high because of mechanical failure of porosimeter.

grain particle and the subcapillary size of the openings. Cores of the Ellenburger samples used in the determinations of effective porosity were tested in a permeameter. In sample No. 72, with an effective porosity of 9 per cent, flow was detected, but the permeability is so small that no attempt was made to measure it. All other samples were found to be impermeable. For all practical purposes the samples of limestone and dolomite from the Riley Mountain sections are impermeable rock.

### COMPOSITION

Of the various methods available for quantitative study of rock composition, quantitative chemical analysis probably is the most highly developed and exact. However, there is often special interest in the mineralogical composition of rocks, and various methods of mineralogical analysis commonly are employed. Commonly it is possible to work from mineralogical composition to approximate chemical composition, and, conversely, to calculate approximate mineralogical composition of a rock from the chemical analysis. Methods that have been used for mineralogical analysis of carbonate rocks include petrographic or microscopical analysis, differential thermal analysis, X-ray analysis, and etching and staining methods.

Five chemical analyses (Table V) were made in the present investigation. Allotting the magnesia (Mg O) to normative dolomite [Ca, Mg $(CO_3)_2$], the bulk compositions in terms of calcite, dolomite, and residual component (Δ) were calculated (Table VI) from the chemical analyses. Samples No. 5 and No. 58 are

TABLE V

CHEMICAL ANALYSES OF SAMPLES OF ELLENBURGER LIMESTONE AND DOLOMITE

(S. S. Goldich, analyst)

| | 5 | 17 | 32 | 58 | 72 |
|---|---|---|---|---|---|
| $CO_2$ | 43.49 | 45.83 | 46.45 | 42.25 | 44.56 |
| CaO | 54.98 | 40.70 | 30.80 | 53.40 | 30.72 |
| MgO | 0.27 | 12.83 | 20.49 | 0.28 | 19.18 |
| $SiO_2$ | 0.53 | 0.32 | 1.70 | 3.72 | 4.44 |
| $Al_2O_3$ | 0.28 | 0.06 | 0.24 | 0.30 | 0.41 |
| $Na_2O$ | 0.01 | n.d. | 0.03 | n.d. | 0.03 |
| $K_2O$ | 0.06 | n.d. | 0.12 | n.d. | 0.23 |
| $H_2O-$ | 0.06 | 0.03 | 0.04 | 0.03 | 0.08 |
| $FeO_3$* | 0.044 | 0.086 | 0.110 | 0.040 | 0.104 |
| $P_2O_5$ | 0.003 | 0.003 | 0.007 | 0.007 | 0.008 |
| $TiO_2$ | 0.011 | 0.002 | 0.013 | 0.003 | 0.021 |
| MnO | 0.003 | 0.007 | 0.014 | 0.005 | 0.010 |
| Total | 99.74 | 99.87 | 100.01 | 100.04 | 99.79 |
| *D*, *t*°/4° | 2.707 | 2.793 | 2.848 | 2.705 | 2.836 |

* Total iron as $Fe_2O_3$.

TABLE VI

CHEMICAL AND DENSITY DATA USED IN PREPARATION OF DENSITY-COMPOSITION DIAGRAM FOR CALCITE AND DOLOMITE (FIG. 3)

| *Sample No.* | *Composition from Chemical Analyses (Table V)* | | | *Density t°/4°* | *Recalculated Composition of Carbonates* | | *Calculated Density of Carbonates** |
|---|---|---|---|---|---|---|---|
| | $CaCO_3$ | $Ca, Mg(CO_3)_2$ | Δ | | *Calcite* | *Dolomite* | |
| 5 | 97.4 | 1.2 | 1.4 | 2.707 | 98.8 | 1.2 | 2.708 |
| 58 | 94.6 | 1.3 | 4.1 | 2.705 | 98.6 | 1.4 | 2.709 |
| 17 | 40.8 | 58.7 | 0.5 | 2.793 | 41.0 | 59.0 | 2.794 |
| 72 | 7.2 | 87.7 | 5.1 | 2.836 | 7.7 | 92.3 | 2.849 |
| 32 | 4.1 | 93.7 | 2.2 | 2.848 | 4.2 | 95.8 | 2.854 |

* A density of 2.62 for the insoluble fraction (Δ) was used in this calculation.

relatively pure limestone with calculated calcite contents of 97.4 and 94.6 per cent, respectively. Samples No. 32 and No. 72 similarly are relatively pure dolomite rock. The calculated dolomite contents are 93.7 and 87.7 per cent, respectively. Sample No. 17 is a calcitic dolomite rock with a calculated composition of 40.8 per cent calcite, 58.7 per cent dolomite, and a residual of 0.5 per cent representing the insoluble fraction. The chief impurity in the analyzed samples is chert,

and the silica ($SiO_2$) contents range from 0.32 to 4.44 per cent. Small amounts of alumina ($Al_2O_3$), 0.06 to 0.41 per cent, and of iron, 0.04 to 0.11 per cent total iron as $Fe_2O_3$, are present. Determinable amounts of alkalies ($Na_2O$ and $K_2O$) were found in three samples tested. Potash predominates over soda, and in the sample of the dolomite rock No. 72 the $K_2O$ content is 0.23 per cent. Phosphorus pentoxide ($P_2O_5$), titania ($TiO_2$), and manganous oxide (MnO) are present in very

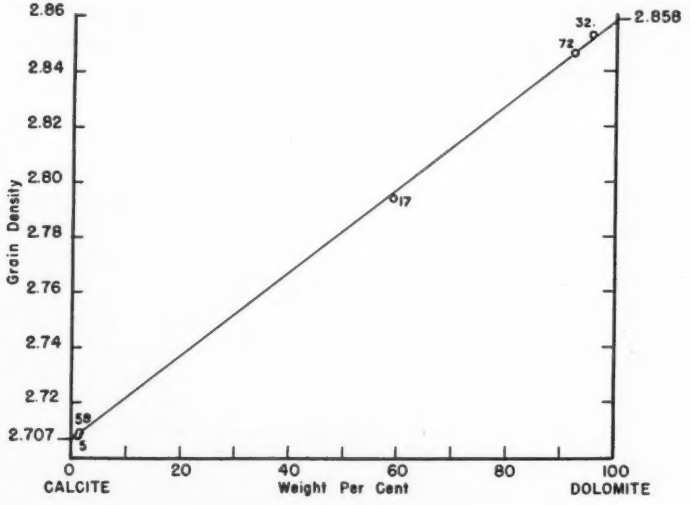



FIG. 3.—Density-composition diagram for determining calcite-dolomite ratio in samples from Riley Mountain Ellenburger section.

small amounts. The content of MnO, ranging from 0.003 to 0.014 per cent, increases with the amount of magnesia or content of dolomite in the samples.

Although additional chemical analyses would be desirable, the limitation of available time precluded obtaining precise chemical data on a large number of samples, and a physical-chemical method for obtaining approximate rock composition was devised. For this method a grain density determination and the percentage of total insolubles are needed. These data permit treating the carbonate rock as a three-component physical system composed of a mechanical mixture of (1) calcite, (2) dolomite, and (3) insoluble components. In the Riley Mountain samples the percentage of insoluble residue ranges from 1 per cent to 19.5 per cent for sample No. 55. If the latter sample is disregarded, the upper limit is 10 per cent, and the average insoluble content is less than 3 per cent. Although small, the insoluble content cannot be neglected, and a group of six samples from a series of channel samples of the Ellenburger analyzed by the Bureau of Economic Geology of The University of Texas was studied to determine the effect of the insolubles on

the grain density. The six samples were subjected to the insoluble residue technique which is outlined in another section of this paper, and the densities of the residues were determined in the fused-silica pycnometer. The densities range from 2.601 to 2.628, averaging 2.618.

Using the average value of 2.618 for the insoluble fraction (Δ), the five analyzed samples (Table V) were corrected to obtain the grain density of the carbonate part of the sample, and from these data (Table VI) a density-composition diagram for mixtures of calcite and dolomite was constructed (Fig. 3). The slope of the line in Figure 3 gives 2.707 for the density of calcite and 2.858 for

TABLE VII

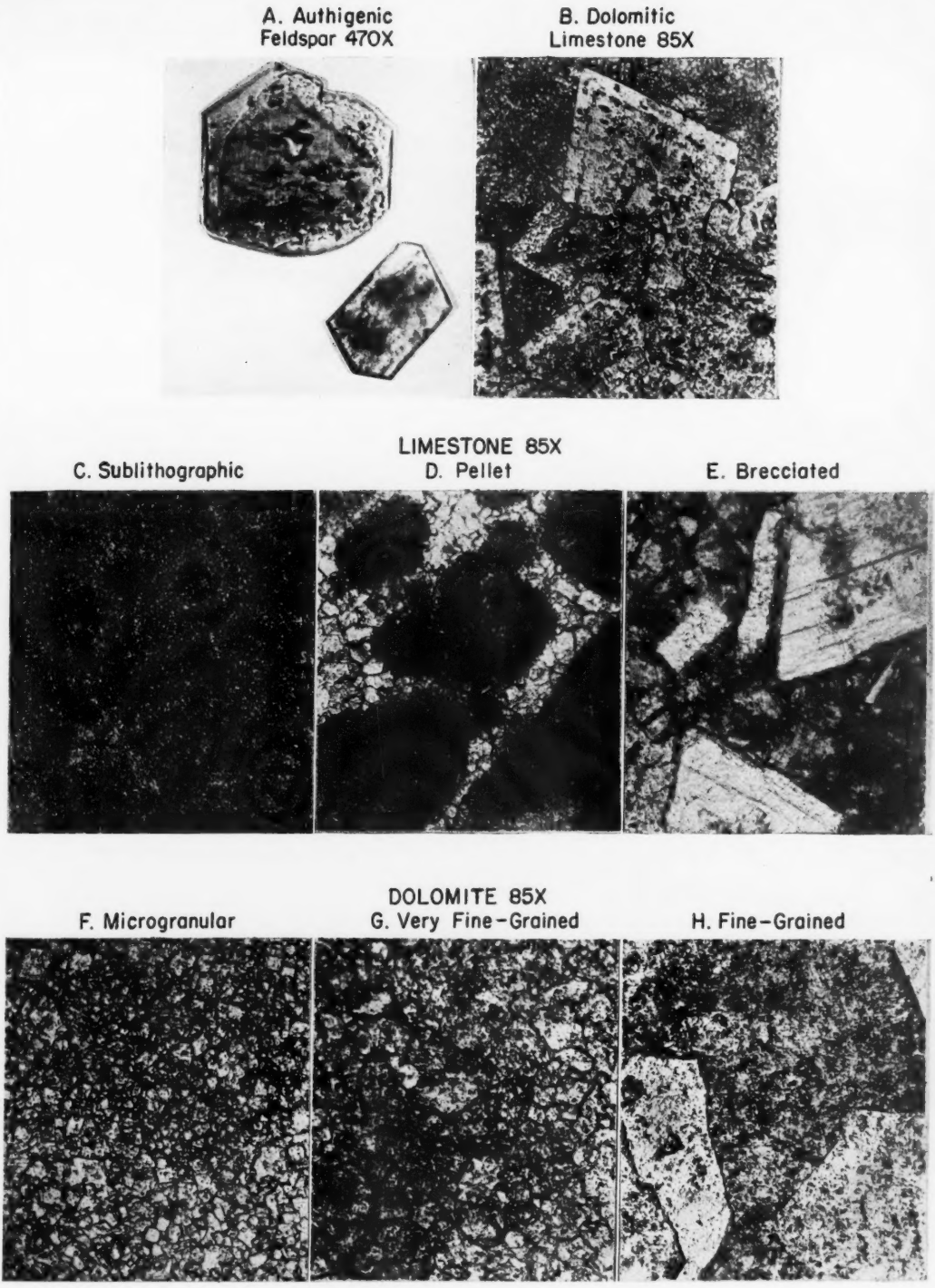
COMPARISON OF ROCK COMPOSITIONS FROM CHEMICAL ANALYSES WITH COMPOSITIONS CALCULATED FROM DENSITY AND INSOLUBLE DETERMINATIONS

| Sample No. | Composition from Chemical Analyses[1] | | | Per Cent Insoluble (Determined) | Density (t°/4°C.) | | | Calculated Composition | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Calcite | Dolomite | Δ | | Rock | Insoluble Residue[2] | Carbonates (Calculated) | Calcite | Dolomite | Δ[3] |
| A | 13.7 | 85.0 | 1.3 | | 2.827 | | 2.830 | 18.3 | 80.4 | 1.3 |
| B | 16.6 | 65.3 | 18.1 | 18.2 | 2.781 | 2.621 | 2.819 | 21.3 | 60.5 | 18.2 |
| C | 10.2 | 87.9 | 1.9 | | 2.828 | | 2.833 | 16.2 | 81.9 | 1.9 |
| D | 21.4 | 76.7 | 1.9 | | 2.809 | | 2.813 | 29.4 | 68.7 | 1.9 |
| E | 7.3 | 58.2 | 34.5 | 34.5 | 2.768 | 2.628 | 2.848 | 4.3 | 61.2 | 34.5 |
| F | 75.0 | 13.2 | 11.8 | 11.6 | 2.713 | 2.615 | 2.727 | 76.5 | 11.9 | 11.6 |
| G | 33.4 | 64.9 | 1.7 | | 2.797 | | 2.801 | 36.9 | 61.4 | 1.7 |
| H | 92.7 | 4.9 | 2.4 | | 2.703 | | 2.705 | 97.6 | — | 2.4 |
| I | 52.5 | 38.7 | 8.8 | 9.0 | 2.748 | 2.601 | 2.763 | 57.3 | 33.7 | 9.0 |
| J | 3.9 | 23.1 | 73.0 | 72.4 | 2.683 | 2.628 | 2.844 | 2.6 | 25.0 | 72.4 |
| K | 52.8 | 43.8 | 3.4 | | 2.758 | | 2.763 | 60.8 | 35.8 | 3.4 |
| L | 63.1 | 32.1 | 4.8 | | 2.749 | | 2.756 | 64.3 | 30.9 | 4.8 |
| M | 97.5 | 0.0 | 2.5 | | 2.702 | | 2.704 | 97.5 | — | 2.5 |
| N | 80.3 | 0.0 | 19.7 | 18.3 | 2.694 | 2.615 | 2.714 | 77.6 | 4.1 | 18.3 |
| O | 43.4 | 51.5 | 5.1 | | 2.764 | | 2.773 | 55.3 | 41.7 | 5.1 |

[1] Analyses by Bur. Econ. Geology, Univ. Texas; excepting B, I, and O by S. S. Goldich.
[2] Average density of 2.62 used for samples for which density of insoluble residue was not determined.
[3] Values from chemical analyses for samples for which insoluble residue was not determined.

the density of dolomite. These values give a working difference of 0.15 for the binary system. With the fused-silica pycnometer the density of a sample of carbonate rock is determinable with a maximum error of ±0.003, and thus the composition of a mixture of calcite and dolomite should be determinable with a probable error of ±4 per cent. In practice this accuracy is not reproducible.

To test the probable accuracy of the physical-chemical method 15 channel samples of the Ellenburger collected and analyzed by the Bureau of Economic Geology were studied. The bulk compositions of the 15 samples calculated from the grain densities and percentages of insolubles, determined or from chemical analyses (Δ), are given in Table VII for comparison with the compositions computed from the chemical analyses. The average deviation for the percentage




PL. I.—Ellenburger photomicrographs (transmitted polarized light).

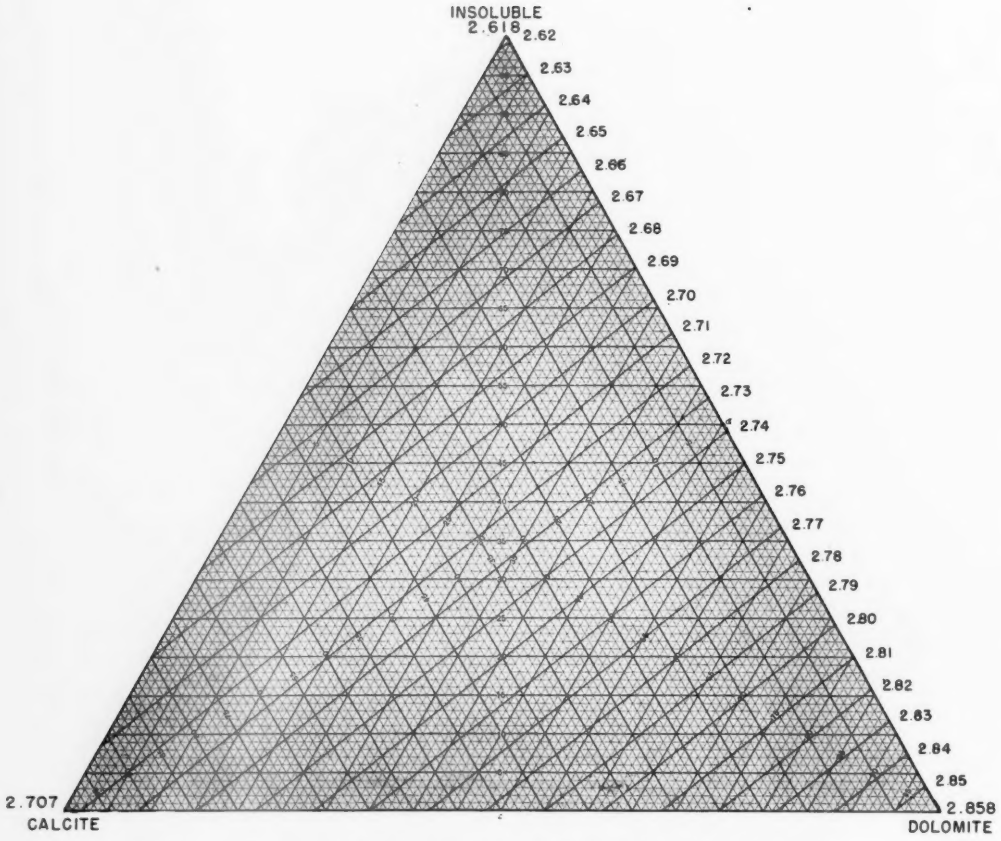



FIG. 4.—Diagram for obtaining approximate bulk composition of Riley Mountain Ellenburger samples from grain density and per cent insoluble.

figures is less than 5 per cent. The greatest deviation is for sample *O* for which the determined composition is 53.2 per cent of calcite and 41.7 per cent of dolomite as compared with 43.4 per cent calcite and 51.5 per cent dolomite calculated from the chemical analysis. This difference is not caused by errors in laboratory technique which are comparatively small. There may be a larger range in density of the insoluble residues than was found in the samples tested. Also, the density of dolomite varies with the composition of the mineral, and $Fe^{++}$, $Mn^{++}$, and to some extent $Ca^{++}$, replace $Mg^{++}$ isomorphously in naturally occurring dolomite. However, in general the density-composition method gives reasonably good results, and although it does not replace precise chemical analysis, the method is rapid and inexpensive, factors of importance in studies of large numbers of samples.

The approximate bulk composition of the Riley Mountain samples can be obtained with reasonable accuracy by referring to the ternary diagram of Figure 4. No calculations are needed, and the position of the sample on the diagram is obtained by simply plotting the grain density (uncorrected) for the sample against the content of insoluble residue.

### INSOLUBLE RESIDUE STUDIES

*History of method.*—H. S. McQueen[21] was the first to study insoluble residues of carbonate rocks on a large scale. He demonstrated the value of insoluble residue examinations of well cuttings in correlating Cambrian and Ordovician limestone and dolomite strata of Missouri. McQueen's work has been continued and applied by other workers in many parts of the United States. The increasing importance of petroleum production from the Ellenburger has given impetus to investigations and use of insoluble residues. The Bureau of Economic Geology of The University of Texas[22] investigated insoluble residues of the Ellenburger, using both surface channel samples and subsurface well samples. M. G. Cheney[23] correlated the Ellenburger in the subsurface of north-central Texas. It is noteworthy that in this work Cheney makes use of the total insoluble percentage, a practice which few other workers have considered worthwhile.

*Procedure.*—In the present investigation, quantitative determinations of insolubles were made by treating 40-gram samples with analytical grade hydrochloric acid, diluted with two parts of water. The samples were broken down to approximately 16-mesh size, and were allowed to stand until the reaction with the acid was complete. More than gentle heating was avoided to minimize attack of silicate minerals by the acid. The fines were decanted into a liter beaker which

[21] H. S. McQueen, "Insoluble Residues as a Guide in Stratigraphic Studies," *Missouri Bur. Geol. and Mines Bien. Rept. State Geologist* (1931), pp. 102–31.

[22] Leo Hendricks, "Subsurface Divisions of the Ellenburger Formation in North-Central Texas," *Univ. Texas Pub. 3945* (1940), pp. 923–68.

[23] M. G. Cheney, "Geology of North-Central Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24 (1940), pp. 71–74.

was filled with water and allowed to stand until the fine material settled. Most of the clear water then was removed by siphoning. This procedure was repeated, and the fines were transferred to a weighed filter paper, washed, and dried in an oven at 105°C. The combined weights of coarse and fine material were used to calculate the percentages of insoluble residue. A comparison of the determined content of insoluble residue with the calculated non-carbonate part (Δ) from chemical analyses can be seen in Table VII.

*Examination of residues.*—The insoluble residues were examined both with the binocular and petrographic microscopes. The relative abundance of the constituents was estimated with the following scale: flood, more than 75 per cent; abundant, 25 to 75 per cent; common, 10 to 25 per cent; rare, less than 10 per cent; and present, only one grain noted. No counts were made of the constituents, and the estimates are rough approximations. A wide-field binocular (30×) was found useful in examining the residues for textural characteristics. With practice, fairly reliable mineralogical determinations can be made with the binocular microscope. A standard petrographic microscope was used in studying the residues in immersion liquids of known refractive indices, and in permanent mounts of Canada balsam. The constituents of the insoluble residues are discussed in detail in a later section.

TABLE VIII

SUMMARY OF MEASUREMENTS FOR TEXTURAL GROUPS

A. ROCK TYPE, TEXTURE, AND COLOR

| *Group No.* | *Number of Samples* | *Rock* | *Texture* | *Predominating Colors* |
|---|---|---|---|---|
| I | 29 | Limestone | Sublithographic, in part pellet | Woodash gray and pearl gray |
| II | 23* | Dolomite | Microgranular to very fine-grained | Varicolored shades of gray, brown, rose, beige |
| III | 11* | Dolomite | Fine-grained | Similar to Group II, including purple |
| IV | 6 | Dolomite | Medium-grained | Similar to Group III |
| V | 2 | Dolomite | Coarse-grained | Brownish gray |
| VI a. | 1 | Cherty limestone | Sublithographic, pellet | Pearl gray |
| VI b. | 2 | Calcitic dolomite | Medium-grained and sublithographic | Gray, pink, and rose |
| VI c. | 1 | Dolomitic limestone | Medium-grained and sublithographic | Light gray with yellow |
| Total | 75 | | | |

TABLE VIII—(*continued*)

B. DENSITY AND POROSITY

| *Group No.* | *Number of Determinations* | $D_0(t°/4°C.)$ | | *Number of Determinations* | *Per Cent Porosity* | |
|---|---|---|---|---|---|---|
| | | *Range* | *Average* | | *Range* | *Average* |
| I | 16 | 2.699–2.709 | 2.705 | 12 | 0.1– 0.7 | 0.5 |
| II | 23* | 2.822–2.848 | 2.836 | 23 | 1.1–12.6 | 4.3 |
| III | 11* | 2.811–2.845 | 2.829 | 11 | 1.3– 7.1 | 3.6 |
| IV | 6 | 2.818–2.846 | 2.827 | 6 | 1.7– 4.3 | 2.6 |
| V | 2 | 2.837–2.839 | 2.838 | 2 | 2.6– 5.0 | 3.8 |
| VI | 4 | 2.698–2.807 | 2.763 | 3 | 0.4– 1.5 | 0.9 |
| Totals | 62 | | | 57 | | |

C. COMPOSITION

| *Group* | *Number of Determinations* | *Insoluble* | | *Number of Determinations* | *Carbonate Ranges* | |
|---|---|---|---|---|---|---|
| | | *Range* | *Average* | | *Calcite* | *Dolomite* |
| I | 29 | 0.4– 6.5 | 2.4 | 16 | 93.9–99.6 | 0.0– 2.9 |
| II | 23* | 1.3– 7.0 | 3.4 | 23 | 2.9–19.4 | 77.7–94.7 |
| III | 11* | 0.4–10.2 | 3.0 | 11 | 2.7–27.2 | 70.0–92.4 |
| IV | 6 | 0.7– 4.0 | 2.4 | 6 | 6.9–20.7 | 77.8–92.4 |
| V | 2 | 0.2– 0.6 | 0.4 | 2 | 11.9–13.0 | 86.8–87.5 |
| VI a. | 1 | 19.5 | | 1 | 74.9 | 5.6 |
| VI b. | 2 | 0.4– 0.6 | 0.5 | 2 | 32.8–42.8 | 56.8–66.5 |
| VI c. | 1 | 1.4 | | 1 | 61.1 | 37.5 |
| Totals | 75 | | | 62 | | |

* Includes one Wilberns formation (Upper Cambrian) sample.

## DATA

The 75 rock samples from the Riley Mountain sections are divided into six groups on the basis of composition and texture. The content of insolubles was determined for all samples. Sixty-two were tested for grain density, and the calcite and dolomite contents calculated. Bulk density was determined for 57 samples, and total porosity calculated. Summaries for the six groups are given in Table VIII.

### GROUP I—LIMESTONE (TABLE IX)

Twenty-nine of the 75 samples, or 39 per cent, are limestone. The samples together with the laboratory data are tabulated in stratigraphic order in Table IX. The predominant color is gray, woodash or a slightly darker shade, pearl gray. A few samples are tannish or brownish gray. The samples generally are dense or sublithographic in texture, with a subconchoidal to conchoidal fracture. Many exhibit a structure with small pellet-like fragments ranging from 1 mm. to 44 mm. in diameter (Pl. I, D). This structure is usually recognizable in the darker color and somewhat coarser texture of the matrix. In samples No. 19, 23, 37, and 47 the pellets are more irregular in size and shape, and these rocks have a con-

glomeratic appearance. Some of the limestone is brecciated (Plate I, E). Yellowish gray and greenish gray argillaceous films and small chert nodules up to 1 cm. in diameter are characteristic of some of the samples.

### GROUP II—MICROGRANULAR AND VERY FINE-GRAINED DOLOMITE (TABLE X)

This group includes dolomitic rocks up to 0.2 mm. in grain size. As used by Cloud and Barnes, microgranular refers to a textural variety less than 0.05 mm. in grain size. Measurement of the microgranular dolomite is uncertain, and because a large percentage of the specimens fall near the division between microgranular and very fine-grained these two textural varieties are not differentiated in the present study (Plate I, F and G). Of the total samples, 23, or approxi-

TABLE IX

GROUP I—LIMESTONE

A. DATA

| *Sample No.* | *Color* | *Density* | *Per Cent Total Porosity* | *Rock Composition Weight Per Cent* | | |
|---|---|---|---|---|---|---|
| | | | | *Determined Insoluble* | *Calculated* | |
| | | | | | $CaCO_3$ | $CaMg(CO_3)_2$ |
| 77 | Light tannish gray | 2.706 | 0.7 | 2.5 | 96.5 | 1.0 |
| 75 | Woodash gray | 2.704 | | 2.1 | 97.9 | |
| 73 | Woodash gray | 2.704 | 0.4 | 3.4 | 96.6 | |
| 70 | Woodash gray and brownish gray | | | 1.3 | | |
| 68 | Light yellowish gray | | | 1.5 | | |
| 67 | Tannish gray | 2.699 | | 3.3 | 96.7 | |
| 66 | Woodash gray | | | 3.3 | | |
| 64 | Pearl gray | 2.704 | 0.3 | 1.9 | 98.1 | |
| 62 | Woodash gray | | | 2.9 | | |
| 60 | Woodash gray with brown | | | 1.5 | | |
| 58 | Woodash gray | 2.705 | 0.4 | 4.1 | 94.6 | 1.3 |
| 57 | Woodash gray | | | 2.9 | | |
| 53 | Brownish gray | | | 0.9 | | |
| 50 | Pearl gray | 2.702 | 0.4 | 4.6 | 95.4 | |
| 48 | Woodash gray | | | 2.3 | | |
| 47 | Light brownish gray | 2.705 | | 1.7 | 98.3 | |
| 45 | Woodash gray | | | 6.5 | | |
| 43 | Woodash gray | 2.705 | 0.4 | 0.4 | 99.6 | |
| 41 | Light pearl gray | | | 3.4 | | |
| 39 | Woodash gray with pink | | | 3.1 | | |
| 37 | Woodash gray | 2.705 | 0.7 | 2.0 | 98.0 | |
| 35 | Woodash gray | | | 2.3 | | |
| 33 | Woodash gray | | | 1.5 | | |
| 27 | Woodash gray | 2.709 | 0.5 | 3.2 | 93.9 | 2.9 |
| 23 | Woodash gray | 2.707 | | 2.7 | 96.3 | 1.0 |
| 21 | Light brownish gray | 2.708 | 0.7 | 1.4 | 97.6 | 1.0 |
| 19 | Pearl gray and woodash gray | 2.705 | 0.6 | 1.6 | 98.4 | |
| 18 | Pearl gray | 2.708 | 0.4 | 0.9 | 97.1 | 2.0 |
| 5 | Greenish and yellowish gray | 2.707 | 0.1 | 1.4 | 97.4 | 1.2 |

TABLE IX—(*Continued*)

B. DESCRIPTION OF INSOLUBLE RESIDUES

| *Sample No.* | *Binocular* | *Petrographic** |
|---|---|---|
| 77 | Granular chert, clear quartz grains | Leucoxene (A); quartz (C); coarse chert (C); feldspar (C) |
| 75 | Uneven porous granular chert, smooth dense chert, sponge spicules | Dense chert (A); spicules (C) |
| 73 | Crinkly granular chert, spongy chert, dense vitreous chert | Chert, clear, dense (F); quartz (R); leucoxene (R) |
| 70 | Finely granular chert, coarsely crystalline chert | Dense chert (F); quartz (R) |
| 68 | Granular chalky chert, crystalline chert, gastropod cast | Dense chert with tiny feldspars (A); coarse chert (C) |
| 67 | Crystalline chert, granular chalky chert, leucoxene | Coarse chert (A); dense chert (R); zircon, leucoxene (R) |
| 66 | Crinkly granular chert | Dense chert with tiny feldspars (F); quartz (R) |
| 64 | Crinkly granular chert, frosted quartz grains | Dense chert with quartz grains and tiny feldspars (A); quartz (C); feldspar (P) |
| 62 | Dense chert, crinkly granular chert | Dense chert with feldspars (A); chalcedony (C) |
| 60 | No coarse residue | Dense chert (F); leucoxene (C); quartz (R); magnetite (R) |
| 58 | Spongy granular chert | Dense chert with feldspars |
| 57 | Crystalline, vitreous chert, crinkly granular chert | Coarse chert (A); dense chert (C); quartz (C); feldspar (R) |
| 53 | Chalky granular chert, crystalline chert, quartz grains | Coarse chert (A); dense chert (A); leucoxene (R); quartz (P) |
| 50 | Crinkly granular chert, chalky chert, frosted quartz grains | Dense cloudy chert with tiny feldspars (F) |
| 48 | Frosted quartz grains | Detrital quartz (F); feldspar (C) |
| 47 | Granular chert, leucoxene, frosted quartz grains | Dense cloudy chert (A); leucoxene (C); quartz (R) |
| 45 | Crinkly granular chert, chalky chert, dense chert | Dense chert (A); coarse chert (C); quartz (C); feldspar (R) |
| 43 | Frosted quartz grains, coarsely granular chert | Quartz (F); feldspar, detrital (C); dense chert (R) |
| 41 | Crinkly granular chert, quartz | Dense chert (A); feldspar (C); quartz (R); garnet (P) |
| 39 | Uneven granular chert, feldspar, tiny frosted quartz grains | Feldspar (A); dense cloudy chert (C); quartz (R); muscovite (P) |
| 37 | Crinkly granular chert, chalky chert, clear quartz grains | Coarse dusty chert (F); feldspar (R); magnetite (R); garnet (P) |
| 35 | Crinkly granular chert, poorly dolomoldic chert | Dense chert (F); feldspar (R) |
| 33 | Crinkly granular chert, frosted quartz grains | Dolomoldic kaolin (A); pyrite (A); feldspar (R); quartz (R) |
| 27 | Granular, poorly dolomoldic chert, frosted quartz grains, leucoxene | Kaolin, intergrown with chert (F); quartz (C); feldspar (R) |
| 23 | Crinkly granular chert, quartz | Dense chert (F); feldspar (C); pyrite |
| 21 | Finely dolomoldic finely granular chert | Dense chert (F); feldspar (R); quartz (R) |
| 19 | Finely granular porous chert, quartz in frosted and clear grains | Dense chert (F); feldspar(R) |
| 18 | Finely dolomoldic finely granular chert, clear quartz | Dense chert (F); quartz (R); magnetite (R); feldspar (P) |
| 5 | Finely granular smooth chert, pyrite | Dense chert with clay mineral (F); quartz (R); muscovite (R); kaolin (P) |

* (F), 75–100 per cent; (A), 25–75 per cent; (C), 10–25 per cent; (R) less than 10 per cent; (P) 1 grain noted.

mately 31 per cent, are classified in this group, placing it second in importance to the limestone. The samples show a variety of colors from very light gray to yellowish gray and brownish gray with subordinate beige, pink, and rose specimens.

### GROUP III—FINE-GRAINED DOLOMITE (TABLE XI)

This group includes finely crystalline dolomite ranging in grain size from 0.2 to 0.6 mm. (Pl. I, H). Eleven samples, or 26 per cent of the dolomite samples and 15 per cent of the total samples, fall in this group. In color these samples range from light gray to brownish gray with brighter shades of yellow, pink, rose, and purple.

### GROUP IV—MEDIUM-GRAINED DOLOMITE (TABLE XII)

This group includes the medium-grained varieties of dolomite with an average grain size between 0.6 mm. and 1.2 mm. Six specimens fall in this group. There are no distinctive colors, and the samples are much like those of Groups II and III.

TABLE X

GROUP II—MICROGRANULAR AND VERY FINE-GRAINED DOLOMITE

A. DATA

| *Sample No.* | *Color* | *Density* | *Per Cent Total Porosity* | *Rock Composition Weight Per Cent* | | |
|---|---|---|---|---|---|---|
| | | | | *Determined Insoluble* | *Calculated* | |
| | | | | | $CaCO_3$ | $CaMg(CO_3)_2$ |
| 76 | Yellowish gray | 2.837 | 4.3 | 2.2 | 10.8 | 87.0 |
| 74 | Light brownish gray | 2.832 | 6.5 | 3.1 | 12.6 | 84.3 |
| 72 | Yellowish gray | 2.836 | 10.0 | 5.1 | 7.2 | 87.7 |
| 71 | Light gray | 2.834 | 3.9 | 2.9 | 10.7 | 86.4 |
| 69 | Yellowish gray | 2.842 | 2.4 | 2.3 | 6.8 | 90.9 |
| 65 | Very light gray | 2.827 | 12.6 | 5.5 | 12.3 | 82.2 |
| 63 | Light brownish gray | 2.826 | 3.2 | 3.4 | 15.5 | 81.1 |
| 61 | Light brownish gray | 2.830 | 4.2 | 4.2 | 11.5 | 84.3 |
| 59 | Light gray | 2.836 | 2.3 | 2.1 | 10.8 | 87.1 |
| 56 | Light gray | 2.827 | 6.7 | 7.0 | 9.3 | 83.7 |
| 54 | Yellowish gray | 2.822 | 4.7 | 2.9 | 19.4 | 77.7 |
| 52 | Light gray and beige | 2.834 | 2.1 | 2.9 | 8.7 | 88.4 |
| 51 | Brownish beige | 2.823 | 1.4 | 3.7 | 15.4 | 80.9 |
| 49 | Light beige | 2.835 | 4.6 | 3.7 | 9.6 | 86.7 |
| 44 | Beige | 2.834 | 2.9 | 5.6 | 6.6 | 87.8 |
| 42 | Rose beige and pink | 2.840 | 3.0 | 3.4 | 6.8 | 89.8 |
| 40 | Salmon pink | 2.842 | 6.7 | 3.2 | 4.8 | 92.0 |
| 38 | Light yellowish gray | 2.828 | 1.5 | 1.3 | 17.8 | 80.9 |
| 34 | Pinkish gray | 2.842 | 4.4 | 4.1 | 4.8 | 91.1 |
| 32 | Light rose gray | 2.848 | 1.9 | 2.2 | 4.1 | 93.7 |
| 30 | Light rose | 2.849 | 1.1 | 2.6 | 2.9 | 94.5 |
| 28 | Rose gray | 2.847 | 2.1 | 2.2 | 3.9 | 93.9 |
| 1* | Brownish gray | 2.847 | 4.4 | 2.4 | 2.9 | 94.7 |

* Wilberns formation, Upper Cambrian.

TABLE X—(*Continued*)

B. DESCRIPTION OF INSOLUBLE RESIDUES

| *Sample No.* | *Binocular* | *Petrographic* |
|---|---|---|
| 76 | Quartz grains | Pyrite (A); feldspar (C); quartz (C); coarse chert (R) |
| 74 | Clear quartz grains, sponge spicules | Leucoxene (A); quartz (C); pyrite (C); spicules (C); dense chert (R) |
| 72 | Smooth dense chert, granular chert, clear quartz | Dense chert (F); chalcedony (R); quartz (R) |
| 71 | Coarse aggregate chert, spicules, clear quartz grains, shards of volcanic glass (?) | Siliceous spicules (A); coarse chert (C); quartz (C); feldspar (C); volcanic glass (?) |
| 69 | Coarse aggregate chert, granular chert, clear quartz grains, leucoxene | Coarse fibrous chert (A); dense chert (C); leucoxene (C) |
| 65 | Subangular quartz grains | Dense chert (A); feldspar (C); quartz (C); leucoxene (C); pyrite (R) |
| 63 | No coarse residue | Feldspar (A); dense chert (A); zircon, muscovite, magnetite (P) |
| 61 | Granular dolomoldic chert | Dense chert (F); quartz (R); feldspar (R); spicules (R) |
| 59 | Smooth chert, granular chert | Dense chert (F) |
| 56 | Frosted quartz, granular chert, smooth chert— leucoxene | Quartz (A); feldspar (C); dense chert (C); magnetite, leucoxene, chalcedony |
| 54 | Finely dolomoldic chert, coarse chert, clear and frosted quartz | Coarse chert, (F); dense chert |
| 52 | No coarse residue | Leucoxene (A); dense chert (C); feldspar (C); quartz (C) |
| 51 | Smooth dolomoldic chert, clear quartz, leucoxene | Dense chert (A); coarse chert (C); feldspar (C); quartz, leucoxene |
| 49 | Finely dolomoldic chert, leucoxene, clear quartz | Leucoxene (A); dense chert (C); magnetite, kaolin, feldspar |
| 44 | Frosted quartz, leucoxene | Leucoxene (A); quartz (A); feldspar, magnetite, apatite |
| 42 | Frosted quartz, spongy chert | Quartz (A); kaolin (C); dense chert (C); feldspar (R) |
| 40 | No coarse residue | Quartz (P); feldspar (P); leucoxene (P) |
| 38 | Coarsely dolomoldic chert, frosted quartz | Leucoxene (A); dense chert (C); feldspar (C); quartz (C) pyrite |
| 34 | Frosted quartz grains, granular chert | Quartz (A); feldspar (C); dense chert (C) garnet (R) |
| 32 | Iron oxides, uneven dolomoldic chert, quartz | Dense chert (F); quartz (R); feldspar (R) |
| 30 | Frosted quartz grains, uneven dolomoldic chert | Quartz (A); dolomoldic kaolin (C); feldspar (C); zircon, muscovite |
| 28 | Smooth dolomoldic chert, frosted quartz | Dolomoldic kaolin (A); quartz (C); feldspar (R) |
| 1* | Rounded quartz grains, smooth dolomoldic chert | Quartz (F); dense chert (C); dolomoldic kaolin (C) |

* Wilberns formation, Upper Cambrian.

GROUP V—COARSE-GRAINED DOLOMITE (TABLE XIII)

Of the samples collected from the Riley Mountain sections, only two are coarsely crystalline with an average grain size exceeding 1.2 mm. Sample No. 6 is light brownish gray and sample No. 4 is light gray.

TABLE XI

GROUP III—FINE-GRAINED DOLOMITE

A. DATA

| Sample No. | Color | Density | Per Cent Total Porosity | Rock Composition Weight Per Cent | | |
|---|---|---|---|---|---|---|
| | | | | Determined Insoluble | Calculated | |
| | | | | | $CaCO_3$ | $CaMg(CO_3)_2$ |
| 78 | Light yellowish gray | 2.831 | 3.3 | 2.1 | 14.7 | 83.2 |
| 46 | Brownish gray | 2.831 | 5.2 | 2.1 | 13.7 | 84.2 |
| 26 | Grayish brown and rose | 2.812 | 1.3 | 5.7 | 20.8 | 73.5 |
| 25 | Light gray with pink and purple | 2.824 | 2.3 | 3.0 | 18.4 | 78.5 |
| 24 | Light gray with pink and purple | 2.822 | 1.6 | 2.4 | 20.5 | 77.1 |
| 13 | Light yellowish gray with purple | 2.811 | 2.3 | 2.8 | 27.2 | 70.0 |
| 11 | Light yellowish gray with purple | 2.845 | 2.8 | 1.7 | 5.9 | 92.4 |
| 9 | Light purplish gray | 2.845 | 5.9 | 1.7 | 5.9 | 92.4 |
| 8 | Very light faintly purplish gray | 2.829 | 7.0 | 10.2 | 2.7 | 87.1 |
| 7 | Very light gray | 2.833 | 4.4 | 0.4 | 15.9 | 83.7 |
| 2 | Light rose gray and purple | 2.839 | 3.5 | 0.4 | 13.0 | 86.6 |

B. DESCRIPTION OF INSOLUBLE RESIDUES

| Sample No. | Binocular | Petrographic |
|---|---|---|
| 78 | Smooth coarsely dolomoldic chert, granular chert, clear quartz grains | Kaolin (A); dense chert (C); leucoxene (C); quartz (R); feldspar, detrital (R) |
| 46 | Dense granular chert | Chert, finely granular to chalcedonic (F) |
| 26 | Smooth dolomoldic chert, chalky chert, frosted quartz grains | Dense clear chert containing authigenic feldspar rhombs (A); feldspar (C); quartz (C); kaolin (C) |
| 25 | Smooth dolomoldic chert, porous chert, slightly frosted quartz, leucoxene | Kaolin (A); finely granular chert (C); feldspar (C); quartz (R); muscovite (R) |
| 24 | Not examined | Kaolin (F); dense chert (C); quartz (C); feldspar (R) |
| 13 | Smooth dolomoldic chert, quartz druse | Dense chert (F); coarse chert (C); chalcedony, quartz, kaolin (R) |
| 11 | Smooth coarsely dolomoldic chert, lucoxene | Dense chert (F); kaolin (C); chalcedony (R); muscovite (R) |
| 9 | Dolomoldic chert | Dense chert (F); kaolin (C) |
| 8 | Smooth dolomoldic chert | Dense chert intergrown with clay mineral (F) |
| 7 | Spongy chert | Coarse granular aggregate chert (F) |
| 2* | Granular chert with quartz aggregate | Quartz aggregate (F); dense chert (C); limonite (R) |

* Wilberns formation, Upper Cambrian.

GROUP VI—MISCELLANEOUS ROCKS (TABLE XIV)

Four samples with variable composition are classified in this group. Sample No. 55 is a cherty limestone with 19.5 per cent of insoluble residue. The specimen

TABLE XII

GROUP IV—MEDIUM-GRAINED DOLOMITE

A. DATA

| Sample No. | Color | Density | Per Cent Total Porosity | Rock Composition Weight Per Cent | | |
|---|---|---|---|---|---|---|
| | | | | Determined Insoluble | Calculated | |
| | | | | | $CaCO_3$ | $CaMg(CO_3)_2$ |
| 36 | Light gray | 2.824 | 1.7 | 2.6 | 18.5 | 78.9 |
| 31 | Mottled light gray and pinkish gray | 2.818 | 2.2 | 3.9 | 20.2 | 75.9 |
| 29 | Light gray with pink | 2.828 | 1.9 | 4.0 | 13.4 | 82.6 |
| 14 | Light brownish gray | 2.823 | 2.5 | 1.5 | 20.7 | 77.8 |
| 12 | Yellowish gray with purple | 2.825 | 2.7 | 1.9 | 18.6 | 79.5 |
| 3 | Light gray | 2.846 | 4.3 | 0.7 | 6.9 | 92.4 |

B. DESCRIPTION OF INSOLUBLE RESIDUES

| Sample No. | Binocular | Petrographic |
|---|---|---|
| 36 | Frosted quartz grains, uneven granular chert | Quartz (A); feldspar, detrital (C); dense chert (C) |
| 31 | Smooth dolomoldic chert, pink dolomoldic chert | Dense chert (F); feldspar (C); quartz (C); kaolin (R) |
| 29 | Frosted quartz, uneven porous chert, smooth dolomoldic chert | Dense chert (A); quartz (A); feldspar (C); kaolin (R); garnet (P) |
| 14 | Smooth dolomoldic chert, oölites, quartz grains | Fine-grained chert with clay mineral (F); kaolin (C); quartz (C) |
| 12 | Smooth dolomoldic chert | Dense, clear chert (F) |
| 3 | Finely granular chert, a granular green mineral, frosted quartz grains | Dense chert, in part chalcedonic (A); glauconite (C); quartz (C); kaolin (C); feldspar (R) |

has the appearance of a pellet conglomerate with pearl gray dense granules in a lighter-colored, coarser-grained matrix. There are small inclusions of light blue-gray subchalcedonic chert. Samples No. 16 and No. 17 are calcitic dolomite. The former is a mottled mixture of light pearl to woodash gray and pink or rose; the latter is a mottled light yellowish gray and woodash gray. Thin sections show large, well zoned crystals of dolomite in the fine-grained calcite (Pl. I, B). The insoluble residue from sample No. 16 is characterized by green fibrous to granular mineral which is glauconite as indicated by X-ray film kindly made by John W. Gruner of the University of Minnesota. Sample No. 15 is a dolomitic limestone very similar in appearance and texture to sample No. 17, excepting for the greater relative abundance of dolomite crystals.

## DISCUSSION OF DATA

### GRAIN DENSITY

The grain densities of the Ellenburger samples reflect mineralogical composition. Because of the relatively low density of the insoluble material compared with

TABLE XIII

GROUP V—COARSE-GRAINED DOLOMITE

A. DATA

| Sample No. | Color | Density | Per Cent Total Porosity | Rock-Composition Weight Per Cent | | |
|---|---|---|---|---|---|---|
| | | | | Determined Insoluble | Calculated | |
| | | | | | $CaCO_3$ | $CaMg(CO_3)_2$ |
| 6 | Light brownish gray with pink and purple | 2.839 | 2.6 | 0.6 | 11.9 | 87.5 |
| 4 | Very light gray with brownish gray | 2.837 | 5.0 | 0.2 | 13.0 | 86.8 |

B. DESCRIPTION OF INSOLUBLE RESIDUES

| Sample No. | Binocular | Petrographic |
|---|---|---|
| 6 | Smooth dolomoldic chert, slightly frosted quartz grains, leucoxene | Kaolin (F); quartz (C); dense chert (R) |
| 4 | No coarse residue | No coarse residue |

TABLE XIV

GROUP VI—MISCELLANEOUS ROCKS

A. DATA

| Sample No. | Color | Density | Per Cent Total Porosity | Rock Composition Weight Per Cent | | |
|---|---|---|---|---|---|---|
| | | | | Determined Insoluble | Calculated | |
| | | | | | $CaCO_3$ | $CaMg(CO_3)_2$ |
| 55 | Pearl gray | 2.698 | 0.4 | 19.5 | 74.9 | 5.6 |
| 17 | Yellowish gray and wood-ash gray | 2.793 | 1.5 | 0.5 | 40.8 | 58.7 |
| 16 | Pearl gray with pink and rose | 2.807 | | 0.6 | 32.8 | 66.5 |
| 15 | Pearl gray and rose gray | 2.762 | 0.8 | 1.4 | 61.1 | 37.5 |

B. DESCRIPTION OF INSOLUBLE RESIDUES

| Sample No. | Binocular | Petrographic |
|---|---|---|
| 55 | Smooth finely dolomoldic chert, vitreous dense chert | Not examined |
| 17 | Two grains finely granular chert | Not examined |
| 16 | Dolomoldic green mineral, granular chert, frosted quartz grains | Glauconite (F); kaolin (C); feldspar (P) |
| 15 | No coarse residue | No coarse residue |

calcite or dolomite, a decrease in grain density may be expected with an increase in the insoluble content. This relationship holds well for the limestone samples, because of their comparatively small content of dolomite. The grain densities of 16 limestone samples (Table IX) show a restricted range from 2.699 to 2.709, averaging 2.705. The effect of the dolomite component in increasing the grain density is clearly shown in the data for three rocks of mixed composition (Table XIV). Sample No. 15 with a grain density of 2.762 has a composition of calcite, 61.1 per cent; dolomite, 37.5 per cent; and insoluble, 1.4 per cent. The densities for samples No. 17 and No. 16 are 2.793 and 2.807, and the calculated dolomite contents are 58.7 per cent and 66.5 per cent, respectively.

An increase in either content of insoluble or of calcite will have the effect of reducing the grain density of dolomite specimens, and in the Riley Mountain samples, density differences are caused largely by variations in calcite content. The density of dolomite approaching the theoretical composition [Ca, Mg $(Co_3)_2$] is approximately 2.858 as extrapolated from the data in Figure 3. The nearest approach to this value was found for samples No. 30 and No. 32, microgranular dolomite samples of Group II, with a grain density of 2.848. From the chemical analysis of sample No. 32 (Table V) the calculated composition is calcite, 4.1 per cent, and dolomite, 93.7 per cent, with a residual ($\Delta$) of 2.2 per cent. As a group the fine-grained dolomite samples (Group III) show the greatest range in grain density, 2.811 to 2.845. This group also shows the greatest ranges in insoluble content, 0.4 to 10.2 per cent, and in calculated calcite content, 2.7 to 27.2 per cent.

On the basis of 40 samples in Groups II, III, and IV, there appears to be a variation of average grain density with grain size (Fig. 5). The microgranular to very fine-grained dolomite samples, ranging in density from 2.822 to 2.846, average 2.836; the fine-grained dolomite averages 2.829; and the medium-grained dolomite specimens, ranging from 2.818 to 2.846, average 2.827. A decrease in grain density accompanies an increase in average grain size. This apparent relationship fails for the coarse-grained dolomite, but this group (V) is represented by two samples only.

### BULK DENSITY AND POROSITY

Determinations of bulk density for 12 limestone samples range from 2.699 to 2.709. The total porosity of the samples ranges from 0.1 to 0.7 per cent, averaging 0.5 per cent. In contrast with the dense compact limestone, the dolomite samples range from 1.1 to 12.6 per cent in total porosity. The largest values for total porosity are for two microgranular dolomite samples. Sample No. 72 contains 10.0 per cent of pore space and has an effective porosity of 9.2 per cent (Table IV). Sample No. 65 has a total porosity of 12.6 per cent. In this same group, however, there is a considerable range of porosity, and sample No. 30 has a porosity of only 1.1 per cent. The coarse-grained dolomite of the lower part of the Tanyard formation is vuggy with cavities measuring several millimeters or more across. The

porosity of sample No. 4 is 5 per cent, and for sample No. 6, 2.6 per cent. These values may not be representative of the true porosity of the coarse-grained dolomite, and larger samples than could be handled in the present investigation may be required for more exact determinations.

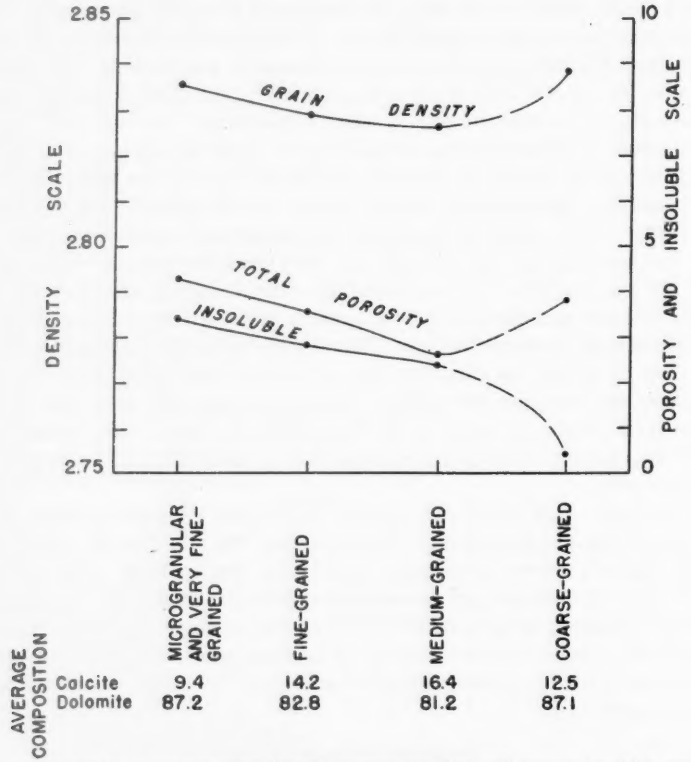



FIG. 5.—Variations of average grain density, average porosity, and average insoluble content with textural groups of dolomite.

## COMPOSITION

The limestone samples, regardless of stratigraphic position, appear to be remarkably uniform in composition. The insoluble content of the 29 samples ranges from 0.4 to 6.5 per cent, averaging 2.4 per cent. A probable minimum calcite content of 94 per cent and a probable maximum calculated dolomite content of 3 per cent are indicated by the density determinations for 16 samples. Although no dolomite component is indicated for 11 samples, the total absence of magnesia is regarded to be unlikely. Analyses of two limestone samples (Table V, 5 and 58)

show 0.27 and 0.28 per cent of MgO. This amount of magnesia is equivalent to slightly more than 1 per cent of calculated dolomite, and such small amounts can not be determined accurately by the density method. Chert is the chief constituent of the insoluble residues; hence, a large insoluble content indicates a correspondingly large silica content. Sample No. 55 (Group VI, Table XIV) represents a cherty limestone with 19.5 per cent of insoluble material.

The dolomite rock samples show greater variability in composition than do the limestone samples. The insoluble content ranges from 0.2 to 10.2 per cent. The average insoluble contents for the textural groups are plotted in Figure 5. The calcite content ranges from 2.7 to 27.2 per cent, the range for the fine-grained dolomite (Group III). The largest average calcite content, however, is for the medium-grained dolomite samples (Group IV) which average 16.4 per cent. The maximum calculated dolomite content is approximately 95 per cent. In a general way the porosity of the dolomite rock samples increases with the relative amount of the Ca, Mg $(CO_3)_2$ component, and as has been pointed out the density of the samples is dependent upon rock composition; hence the variations plotted in Figure 5 probably reflect variations with average rock composition rather than with grain size. Additional samples, particularly of the coarse-grained dolomite, are needed to determine whether or not the compositional differences suggested by the data for the different textural groups are real or apparent.

### INSOLUBLE RESIDUES

*Principal features.*—Chert is the chief constituent of the insoluble residues of the Ellenburger limestone and dolomite. The chert ranges from dense or cryptocrystalline to coarsely granular and fibrous or chalcedonic varieties. Other minerals identified in the residues are quartz, feldspar, clay mineral, glauconite, hematite, limonite, leucoxene, magnetite, pyrite, muscovite, zircon, tourmaline, garnet, and apatite. Brief descriptions of the constituents follow.

*Chert.*—Very fine-grained to dense or cryptocrystalline chert is the predominant constituent of the insoluble residues. Thin "crinkly" flakes and irregular fragments of the dense chert are characteristic of the limestone samples. Dolomoldic chert is characteristic of much of the dolomite, but other varieties of chert also are found. The dolomoldic variety resulting from the solution and removal of carbonate rhombs in the acid treatment is comparatively rare in the limestone samples, and the molds typically are much smaller than in the dolomite chert. The dense chert grades to finely crystalline and granular varieties. It is clear to dusty or cloudy in transmitted light and is essentially non-polarizing. The cloudy appearance is caused by numerous included clay mineral particles, and commonly minute pseudo-rhombic crystals of authigenic feldspar can be seen under high magnification. The granular and fibrous varieties of chert are readily distinguished with the petrographic microscope. The chert is predominantly white and more rarely gray, yellow, or tan.

A distinctive type of chert, viewed with the binocular microscope, is a fine-

grained, translucent, non-porous variety which appears to be more common in the Gorman and Honeycut formations than in the Tanyard.

*Quartz.*—Quartz is second to chert in abundance in the insoluble residues. It occurs in subangular to well rounded grains which may be clear or frosted in appearance. These detrital grains range from 0.03 mm. to 0.5 mm. in diameter, or from silt to medium sand grains with most of the grains probably falling in the fine sand size ($\frac{1}{8}$–$\frac{1}{4}$ mm.). There are inclusions of apatite, zircon, and other minerals in many grains. Some of the quartz grains show secondary enlargement, and druses of finely crystalline quartz coat chert fragments. The quartz of these druses developed in the sediment probably before final lithification and is classed as authigenic quartz.

*Clay minerals.*—Kaolinite is a common to abundant mineral in many of the residues. The kaolin occurs in comparatively large flaky grains which commonly are dolomoldic, and in binocular examinations this mineral can be confused easily with dolomoldic chert. In Canada balsam mounts the moderately high relief and the low but distinct interference colors between crossed nicols serve to identify the kaolinite. The dolomolds mark the kaolinite of both limestone and dolomite residues and suggest that the clay mineral was developed or crystallized contemporaneously with the growth of the calcite or dolomite crystals.

Intergrown with much of the chert is a clay mineral which gives the chert a cloudy or dusty appearance. This clay mineral in some residues possesses rather high birefringence suggesting montmorillonite-beidellite clay minerals or possibly a potash-bearing clay mineral. Positive identification could not be made.

*Feldspar.*—Two types of feldspar occur in the samples of the Ellenburger from the Riley Mountain sections. Samples from above the Tanyard-Gorman contact contain appreciable quantities of detrital alkalic feldspar, chiefly orthoclase and microcline. In addition to the detrital feldspar, there is authigenic or sedimentary feldspar which was developed in the limestone and dolomite of the Ellenburger.

The authigenic feldspar is of two types: (1) euhedral crystals of pseudorhombohedral habit generally extremely small and measuring a few microns in greatest dimension but attaining sizes up to 0.09 mm. in length, and (2) overgrowths or secondary enlargements on detrital grains of feldspar (Pl. I A). The authigenic feldspar appears to be adularia or potash-rich feldspar. The small euhedral crystals commonly are intergrown with chert and in one residue were noted in flaky granular kaolinite. In occurrence and in composition the authigenic feldspar of the Riley Mountain sediments is similar to other occurrences described in detail by Tester and Atwater[24] and to overgrowths or secondary enlargements described by Goldich.[25] This is the first recorded occurrence of authigenic feldspar from Texas.

[24] A. C. Tester and G. I. Atwater, "The Occurrence of Authigenic Feldspars in Sediments," *Jour. Sed. Petrology*, Vol. 4 (1934), pp. 23–31.

[25] S. S. Goldich, "Authigenic Feldspar in Sandstones of Southeastern Minnesota," *Jour. Sed. Petrology*, Vol. 4 (1934), pp. 89–95.

*Glauconite.*—A green, fibrous to granular, dolomoldic mineral is abundant in the residue from sample No. 16, a calcitic dolomite from near the base of the calcitic facies in the upper part of the Staendebach member of the Tanyard formation. X-rays indicate glauconite, but the dolomoldic habit is exceptional, and probably is similar in origin to the dolomolds of the kaolin described in a preceding paragraph. Glauconite also occurs in sample No. 3, a medium-grained dolomite from near the base of the Tanyard formation, but is rare in other samples.

*Iron oxides and leucoxene.*—Secondary iron oxides, limonite and hematite, and leucoxene are not abundant. They probably are alteration products of iron sulphide, magnetite and ilmenite, or titaniferous magnetite. The leucoxene commonly is in spongy, white, yellow, and yellowish or reddish brown opaque aggregates.

*Other minerals.*—Other minerals identified in scattered residues, and as a whole rare in the Ellenburger samples, are apatite, garnet, magnetite, muscovite, tourmaline, and zircon. These minerals do not require description, except for a few comments. Muscovite probably is the most common of the group and occurs in relatively large plates and flakes. Well rounded grains and crystals of zircon are present. The largest well formed crystal measured 0.13 mm. in length. The garnet shows poor dodecahedral cleavage. Pyrite is in part altered to limonite, and pseudomorphs are common. Although pyrite and its alteration product are fairly abundant in a few samples, the sulphide is unimportant in the section as a whole.

*Unidentified minerals.*—The suite of minerals given above includes the common and readily identifiable constituents. There are in addition rare minerals which were not determined. Heavy-liquid separations were not made in the present investigation, and such concentrations would be desirable and undoubtedly would permit identification of additional mineral species.

*Special features.*—Siliceous oölites occur in the residue from sample No. 14, and siliceous spicules were noted in a number of samples from the upper part of the Honeycut formation.

## STRATIGRAPHIC VARIATIONS OF PHYSICAL AND CHEMICAL PROPERTIES

### COMPOSITION

*Problems of sampling.*—The sampling of large and variable rock masses for quantitative study presents numerous problems that commonly must lead to a compromise between the ultimate end of the sampling—to fully represent the rock mass—and the available facilities and time. Channel sampling, a method used by the Bureau of Economic Geology to obtain samples of the Ellenburger for chemical analysis, probably is the closest approach to a continuous core in representing the stratigraphic succession. However, for the present investigation hand specimens were collected for determination of bulk density and porosity. As the number of specimens that could be studied was limited, spot sampling was

a necessity. To illustrate the difference between spot sampling and channel sampling in representing composition, the Riley Mountain samples have been plotted on a triangular composition diagram (Fig. 6) on which also is shown the composition of analyzed channel samples (Table VII) from other sections of the Ellenburger. The channel samples show greater variety of composition, because

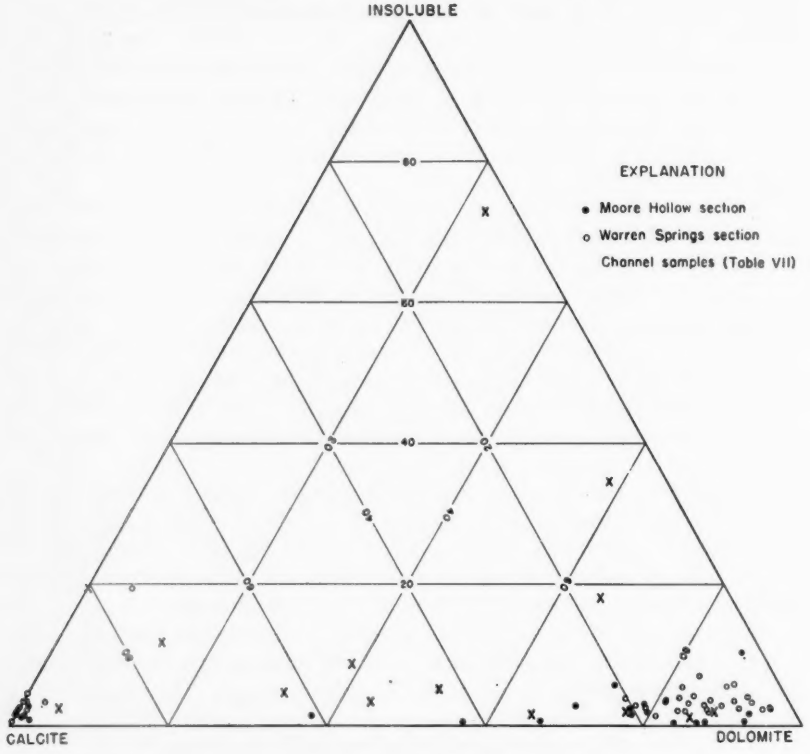



FIG. 6.—Diagram showing composition of Ellenburger samples.

they cut across interbedded limestone and dolomite and also include the chert along the line of sampling.

*Variations.*—Although the hand specimens fail to represent the relative abundance of rock types in the Moore Hollow and Warren Springs sections quantitatively, they bring out the compositional and textural differences and changes. Each of the lithologic units recognized by Cloud was sampled, and the distribution of the samples illustrates the distribution and the frequency of alternation of limestone and dolomite in various parts of the stratigraphic section.

In the Moore Hollow section (Fig. 7) the Threadgill member of the Tanyard formation is divided into lower and upper dolomitic facies with a middle calcitic unit. The three subdivisions are of nearly equal thickness and aggregate 250 feet. The overlying Staendebach member consists of a lower dolomitic facies 232 feet thick and an upper calcitic facies 121 feet thick. The total thickness of the Tanyard formation is 603 feet. The three samples, Nos. 15, 16, and 17, which show mixed composition, lie stratigraphically in a zone which marks the transition from the dolomitic to the calcitic facies of the Staendebach member.

The lower 214 feet of the Gorman formation in the Warren Springs section (Fig. 8) is a dolomitic facies. Along the line of section there is very little limestone in this part of the Gorman, excepting for the 17-foot interval between 169 and 186 feet above the Tanyard-Gorman contact. The upper calcitic facies of the Gorman formation is 242 feet thick and along the line of section is composed of about equal amounts of limestone and dolomite. The total thickness of the Gorman formation is 456 feet. The Honeycut formation in the Warren Springs section is 453 feet thick and consists of relatively thin interbedded limestone and dolomite, except for the upper 100 feet, which along the line of section is dolomite with a few thin beds of limestone.

The Ellenburger group on Riley Mountain has a total thickness of about 1,500 feet in which dolomite is predominant, and probably not more than one-third of the measured section is limestone. Chert occurs throughout the entire section in nodules and in thin layers or lenses as well as in finely disseminated form as revealed by the insoluble residues of both limestone and dolomite. No estimate of the relative abundance of the chert can be made for the whole section.

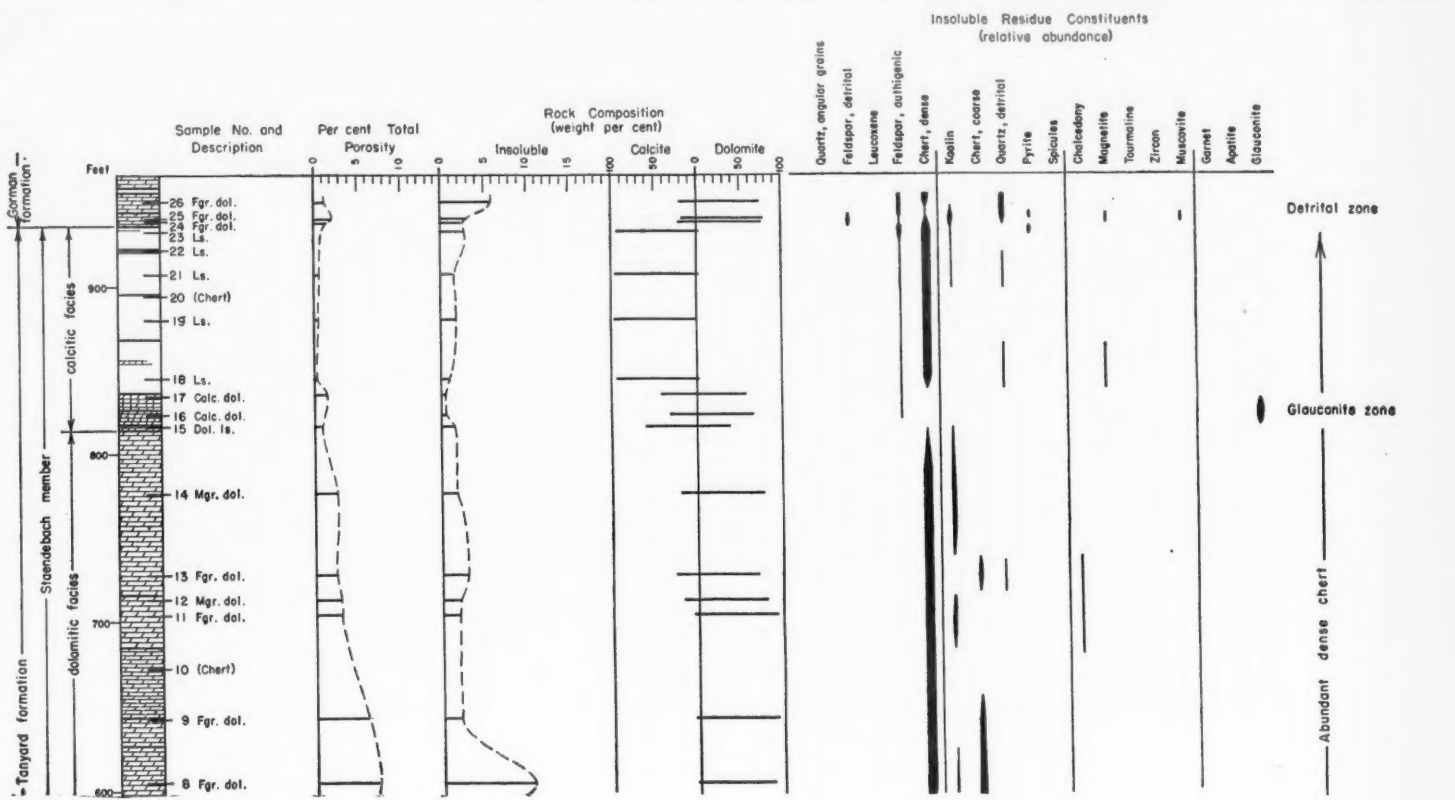
### TEXTURAL VARIATIONS

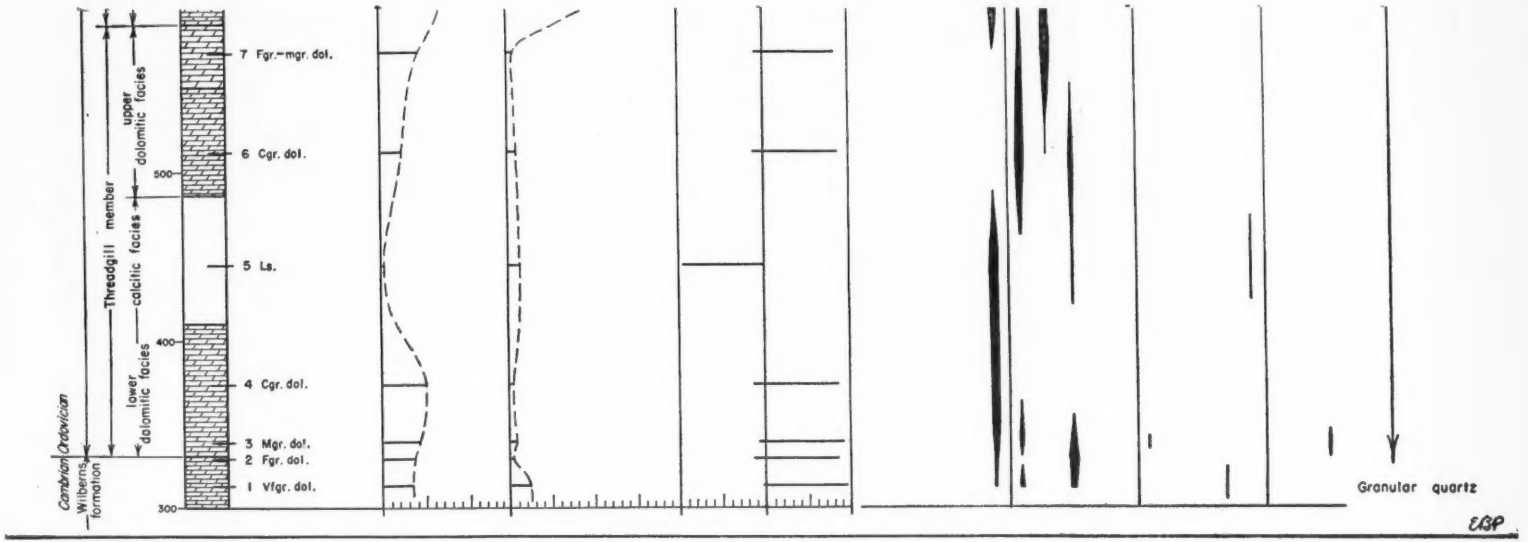
The Ellenburger limestone is markedly uniform throughout the section in its dense sublithographic texture. In contrast, the dolomite shows certain textural variations with stratigraphic position. The coarse-grained dolomite is limited to the lower part of the Tanyard formation; the microgranular and very fine-grained variety appears to be restricted to the Gorman and Honeycut formations; whereas, the fine- to medium-grained types range from bottom to top of the section. The distribution supports the conclusions of Cloud, Barnes, and Bridge[26] relative to the occurrence of the microgranular dolomite and also their use of this distribution in locating the Tanyard-Gorman contact. Above this contact the microgranular and very fine-grained dolomite is distributed rather uniformly throughout the Gorman and Honeycut formations.

### POROSITY

In the dolomitic rocks variations of porosity with stratigraphic position are suggested by the data plotted in Figures 7 and 8. Samples from the Tanyard

[26] P. E. Cloud, Jr., V. E. Barnes, and Josiah Bridge, "Stratigraphy of the Ellenburger Group in Central Texas—A Progress Report," *Univ. Texas Pub. 4301* (1945), pp. 133–77.


Tanyard formation
Gorman formation
Staendebach member
calcitic facies
dolomitic facies
Feet
900
800
700
600
Sample No. and Description
26 Fgr. dol.
25 Fgr. dol.
24 Fgr. dol.
23 Ls.
22 Ls.
21 Ls.
20 (Chert)
19 Ls.
18 Ls.
17 Calc. dol.
16 Calc. dol.
15 Dol. ls.
14 Mgr. dol.
13 Fgr. dol.
12 Mgr. dol.
11 Fgr. dol.
10 (Chert)
9 Fgr. dol.
8 Fgr. dol.
Per cent Total Porosity
0 5 10
Rock Composition (weight per cent)
Insoluble
0 5 10 15
Calcite
100 50 0
Dolomite
0 50 100
Insoluble Residue Constituents (relative abundance)
Quartz, angular grains
Feldspar, detrital
Leucoxene
Feldspar, authigenic
Chert, dense
Kaolin
Chert, coarse
Quartz, detrital
Pyrite
Spicules
Chalcedony
Magnetite
Tourmaline
Zircon
Muscovite
Garnet
Apatite
Glauconite
Detrital zone
Glauconite zone
Abundant dense chert




EXPLANATION

Abbreviations: ls., limestone; dol., dolomite; micro., microgranular; vfgr., very fine-grained; fgr., fine-grained; mgr., medium-grained; cgr., coarse-grained.

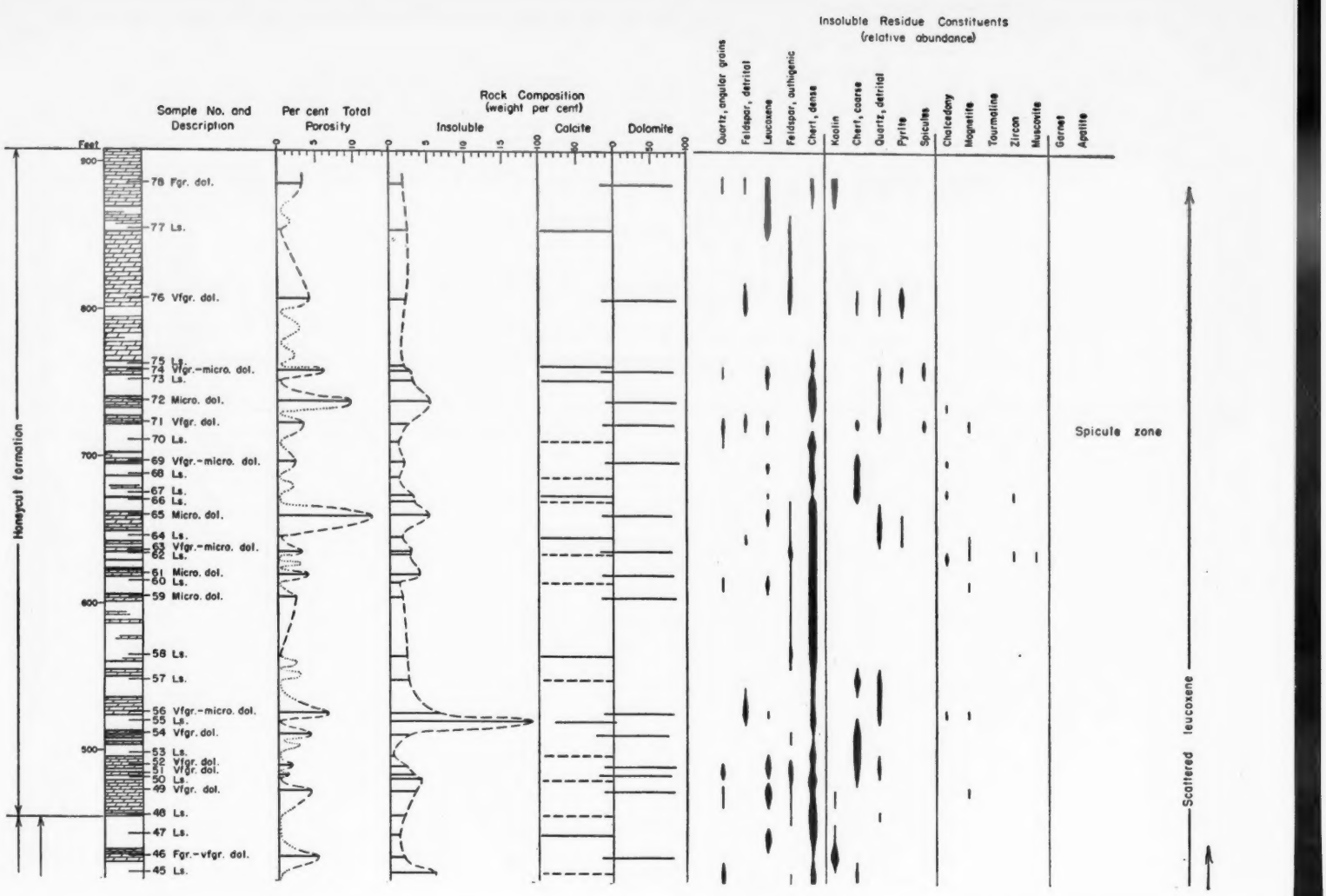
Symbols: Interpretative line connecting determined points; dotted where inferred.

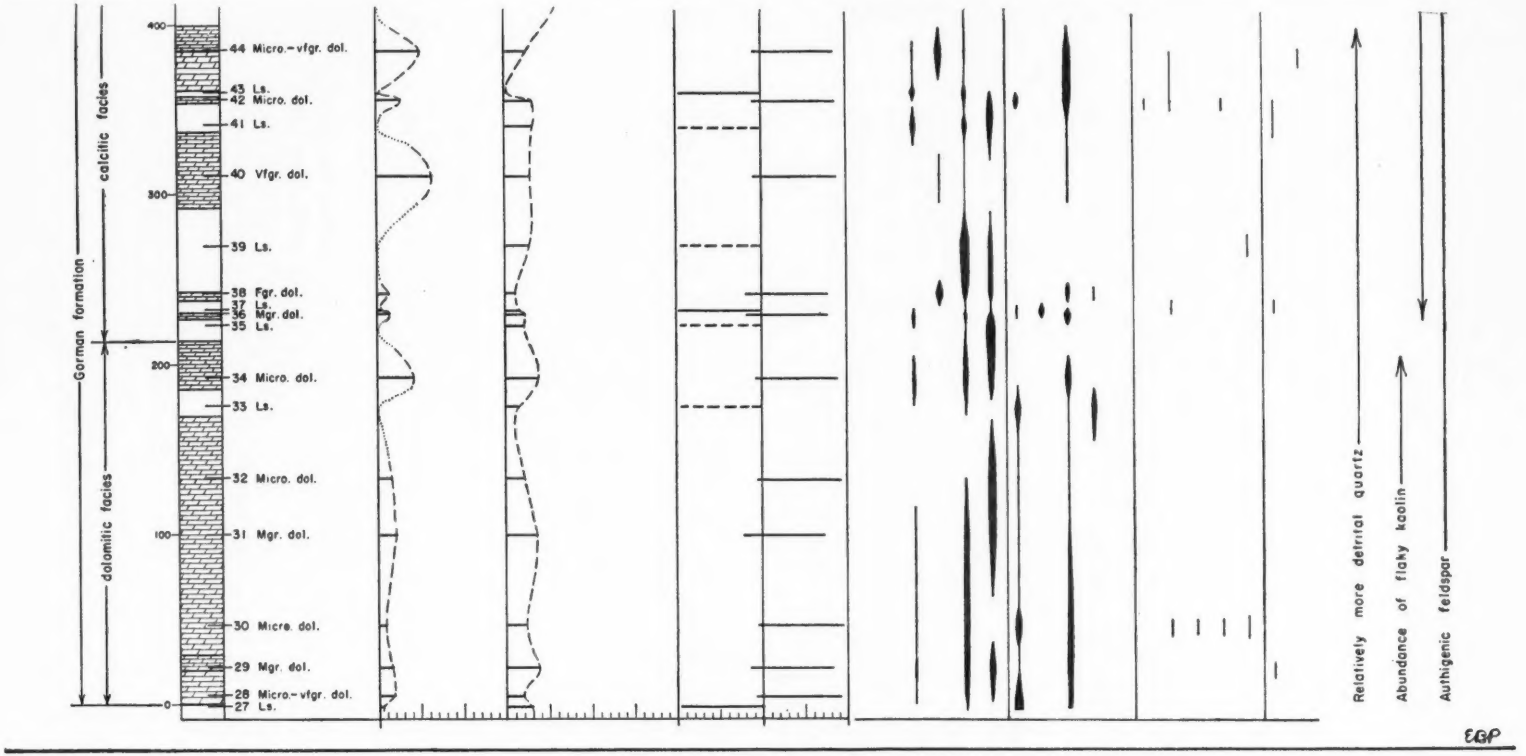
Inferred composition.

Relative abundance indicated by width, from present to flood.

Vertical scale: feet above base of stratigraphic section.

FIG. 7.—Moore Hollow section of Ellenburger group on Riley Mountain, Llano County, Texas, showing lithologic units, position of samples, and laboratory data.


Sample No. and Description
Per cent Total Porosity
Rock Composition (weight per cent)
Insoluble
Calcite
Dolomite
Insoluble Residue Constituents (relative abundance)
Quartz, angular grains
Feldspar, detrital
Leucoxene
Feldspar, authigenic
Chert, dense
Kaolin
Chert, coarse
Quartz, detrital
Pyrite
Spicules
Chalcedony
Magnetite
Tourmaline
Zircon
Muscovite
Garnet
Apatite
Feet
Honeycut formation
78 Fgr. dol.
77 Ls.
76 Vfgr. dol.
75 Ls.
74 Vfgr.-micro. dol.
73 Ls.
72 Micro. dol.
71 Vfgr. dol.
70 Ls.
69 Vfgr.-micro. dol.
68 Ls.
67 Ls.
66 Ls.
65 Micro. dol.
64 Ls.
63 Vfgr.-micro. dol.
62 Ls.
61 Micro. dol.
60 Ls.
59 Micro. dol.
58 Ls.
57 Ls.
56 Vfgr.-micro. dol.
55 Ls.
54 Vfgr. dol.
53 Ls.
52 Vfgr. dol.
51 Vfgr. dol.
50 Ls.
49 Vfgr. dol.
48 Ls.
47 Ls.
46 Fgr.-vfgr. dol.
45 Ls.
Spicule zone
Scattered leucoxene




EXPLANATION

Abbreviations: ls., limestone; dol., dolomite; micro., microgranular; vfgr., very fine-grained; fgr., fine-grained; mgr., medium-grained; cgr., coarse-grained.

Symbols: Interpretative line connecting determined points; dotted where inferred.

Inferred composition.

Relative abundance indicated by width, from present to flood.

Vertical scale: feet above base of stratigraphic section.

FIG. 8.—Warren Springs section of Ellenburger group on Riley Mountain, Llano County, Texas, showing lithologic units, position of samples, and laboratory data.

formation show a range in porosity from 2.3 per cent to 7.1 per cent, the maximum value obtained for sample No. 8 from the basal unit of the Staendebach member. From this point a progressive decrease in per cent of porosity is indicated by the samples up to the Tanyard-Gorman contact. The lower dolomitic facies of the Gorman formation is characterized by a small but uniform porosity. Determinations on samples from the calcitic facies of the Gorman formation and from the Honeycut formation show an alternation of relatively high and low porosity which is controlled by the alternation of the dense, non-porous limestone with the microgranular and very fine-grained dolomite. In the dolomite rocks correlation of relatively high porosity with large content of insolubles (Fig. 5) also is shown on Figures 7 and 8. The relatively greater porosity of the microgranular dolomite clearly influences the stratigraphic variations of porosity indicated by the samples.

### INSOLUBLE RESIDUES

Insoluble residues are now being used in the correlation of subsurface samples of the Ellenburger. For this reason the stratigraphic variations of the insoluble residues from the hand specimens have some interest even though they are not quantitatively representative of the Moore Hollow and Warren Springs sections. The stratigraphic distribution and relative abundance of minerals in the residues are shown on Figures 7 and 8. The significant changes in the residues and mineralogical horizon markers which may have possible correlative value are indicated.

Residues of the Tanyard formation consist almost wholly of dense chert, which commonly is intergrown with a clay mineral. The very fine-grained dolomite, sample No. 1, and the fine-grained dolomite, sample No. 2, collected just below the Cambrian-Ordovician contact from the Wilberns formation have abundant finely granular detrital quartz which is rare in samples from above the contact. Likewise, quartz and other detrital minerals appear in abundance in samples from above the Tanyard-Gorman contact. These insoluble residue characteristics support the formational divisions made by Cloud in the Riley Mountain sections.

In the residue from sample No. 16, in the calcitic facies of the Staendebach member and approximately 113 feet below the Tanyard-Gorman contact, glauconite is the flood mineral. A small amount of glauconite also occurs in the residue from sample No. 3 at the base of the Threadgill member, but it is absent or only sparingly present in other samples.

The residues of the Gorman and Honeycut formations are marked by their variety of constituents and by a suite of detrital minerals. In addition to the dense chert found throughout the section, but only sparingly present in the upper 100 feet of the Honeycut formation, there is an appreciable amount of coarsely granular chert in the residues. Detrital quartz, feldspar, and more rarely heavy accessory minerals, such as zircon, garnet, tourmaline, magnetite, and apatite, are characteristic of the residues of the samples throughout the Warren Springs

section. Finely granular kaolin in rather large flakes or plates, commonly showing dolomolds, is abundant, particularly in the lower part of the Gorman. Secondary iron oxides and leucoxene are characteristic of the upper Gorman and of the Honeycut residues. Authigenic feldspar and particularly overgrowths or secondary enlargements of detrital grains characterize the lower Gorman. Authigenic feldspar in appreciable quantities is first noted in residues of samples from near the Tanyard-Gorman contact and persists throughout most of the Gorman formation. Siliceous spicules occur in two residues from the Honeycut formation and probably mark a zone approximately 200 feet below the top of the Honeycut formation.

## CONCLUDING REMARKS

It is believed that detailed studies with the application of present methods and techniques, modified and improved, will lead to a better and more fundamental understanding of carbonate rocks, their origin, diagenesis, lithification, and alteration. The present investigation is essentially an exploratory one, and the results are of interest primarily for the possibilities they suggest, rather than for the conclusions which can be drawn from them. The insoluble residue technique, utilizing the petrographic microscope and other available tools for mineral identification, applied to the study of channel samples and drill-hole cuttings and cores may well lead to the development of usable criteria for correlation purposes.

The alternation of thin limestone and dolomite beds and the gradations from limestone to dolomite which characterize the Ellenburger strata of the Llano uplift are difficult to explain. The non-porous, impermeable character of the dense limestone precludes the large-scale development of dolomite by replacement as a result of groundwater movements. Although no data are available by which the primary origin of the dolomite by direct precipitation from sea water can be ruled out, the diagenetic replacement of calcium carbonate on the sea floor seems to be an adequate mode of origin. Dolomoldic chert, kaolin, and glauconite are interpreted by the writers as diagenetic features related to the crystallization and growth of dolomite crystals. These minerals, together with pyrite, secondary feldspar, and secondary quartz such as the druses and enlargements on detrital grains, may be classed as authigenic minerals, although it is not possible to demonstrate fully that development was *in situ*.

The subject of diagenetic changes in calcareous sediments has been reviewed by Thiel.[27] Progress has been made in this field of investigation, but the conditions of origin of minerals such as authigenic feldspar and glauconite are not fully understood, and the genesis of dolomite remains one of the most interesting of sedimentary problems. Probably little is to be gained by further reworking of the information already available, and energies are best directed to development of new approaches and to the accumulation of new and better field and laboratory data.

[27] G. A. Thiel, "Diagenetic Changes in Calcareous Sediments," *National Research Council Report of the Committee on Sedimentation, 1940-1941* (1941), pp. 81–109.

Within recent years increasing attention has been given to porosity and reservoir conditions in carbonate rocks. Openings in limestone and dolomite probably originate in a number of ways. It seems likely that in some cases composition may have been the determining factor. In many oil pools the accumulation of petroleum in carbonate-rock reservoirs appears to be related to fracture porosity and structure. It seems likely that rock composition and possibly also rock texture may have been factors in determining the type of deformation produced. There is some information on the strength of carbonate rocks and on their deformation under controlled conditions, but there appear to be few data which can be correlated with the physical and chemical properties of the tested rock.

Movements of water through rock openings, primary or secondary, may cause local solution and also deposition. The relative solubility of carbonate rock as influenced by composition and by grain size is a field worthy of investigation.

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VOL. 31, NO. 11 (NOVEMBER, 1947), PP. 2021-2029, 4 FIGS.

# STRATIGRAPHIC CONVERGENCE PROBLEMS IN OIL-FINDING[1]

ROBERT M. SWESNIK[2] AND ROBERT R. WHEELER[3]
Oklahoma City, Oklahoma

## ABSTRACT

Onlap, involving loss of beds at the base of a transgressing sequence, and truncation, by which beds are beveled off by differential erosion, are regarded here as the important factors in stratigraphic convergence. These processes are quantitatively formulated with reference to the rates of dip of (1) the upper beds, (2) the unconformity, and (3) the lower beds. The applications of convergence formulae to reconstructing paleogeology, to locating belts of wedge-out reservoir rocks, and to detecting structural anomalies are discussed with especial emphasis on the possibilities for cooperation between seismologist and geologist in finding stratigraphic traps.

## INTRODUCTION

The search for stratigraphic oil traps should be accelerated as much by an appreciation among geologists of the factors responsible for porosity changes and convergence phenomena in reservoir strata as by the increasing difficulties of finding new structural traps. Recent discovery of a series of stratigraphic-type oil fields along the east flank of the Anadarko basin of Oklahoma including the truncated Hunton limestone production of West Edmond and the Pennsylvanian, Deese, sand pools in an arc around the Pauls Valley uplift has led to the prediction that more oil will be found trapped primarily by stratigraphic rather than structural factors in this province. Favoring this viewpoint, the writers are encouraged to review the mechanics of stratigraphic convergence and its relation to non-convergent sedimentary traps.

This joint undertaking has resulted from discussions between the writers and many other geologists in Oklahoma City whose contributions are here gratefully acknowledged. Credit for numerous ideas regarding the application of seismic techniques to finding convergence traps is due Lynn B. Trombla.[4] Swesnik's particular contributions, concerning the formulation of the components of convergence by which onlap and truncation can be differentiated in subsurface problems, and wedge-out belts can be areally predicted, result from his West Edmond[5] and Southwest Antioch[6] studies. Efforts to expand these concepts and fit them into a genetic approach to problems of oil-finding are part of Wheeler's forthcoming paper on the "Geology and Oil Possibilities of the Anadarko Basin."

[1] Manuscript received, July 30, 1947.

[2] Geologist, Anderson-Prichard Oil Corporation.

[3] Consulting geologist.

[4] President, Central Exploration Company.

[5] Robert M. Swesnik, "Geology of West Edmond Oil Field, Oklahoma," manuscript accepted for publication in forthcoming *Structure of Typical American Oil Fields*, Vol. III, Amer. Assoc. Petrol. Geol.

[6] ———, "Southwest Antioch—Development Report," *Oil and Gas Jour.* (April 19, 1947), p. 82.

CONVERGENCE CONCEPTS

While the writers have no intention of critically reviewing the imposing mass of publications on stratigraphic traps to add another classification to an over-classified subject, they are obliged to comment that in none of the many published schemes of taxonomy has the mechanics of onlap or its relation to truncation been adequately demonstrated. Neither do they intend to imply that a genetic instead of a morphologic approach to the description of stratigraphic traps is a cure-all for classifying the vast range of possible types but rather to suggest that most of the traps formed by stratigraphic convergence are most reasonably approached from the genetic, or historical geologic, viewpoint. From this point of view, they are first interested in ascertaining to what extent previous work has analyzed the processes and significance of onlap and truncation in creating stratigraphic traps.

Sanders'[7] approach has been concerned primarily with the separation of traps into (I) Structural, (II) Stratigraphic, and (III) Combination Structural-Stratigraphic traps in which classification any case of "simple" convergence would fall into his subclass A(1) defined as follows:[8]

> Trap wholly due to the pattern of *areal* development of a wedging permeable zone, with no structural deformation involved in the trapping other than regional tilt. [Includes eroded, overlapped and sealed reservoir edges]

His definition fails to differentiate the genetically separate processes of onlap and truncation as factors in creating stratigraphic convergence. While it was Sanders' intention that this broad classification be offered "for every-day usage" its utility would, in the writers' opinion, be enhanced more by an investigation of the stratigraphic processes involved in the "catch-all stratigraphic trap terminology" than in stressing the structural factors.

More recently Brod[9] attempted to revise trap classifications from a combined morphological (general shape of reservoir) and functional (fluid behavior) approach into three classes, (I) Bedded, (II) Massive, and (III) Zonal. Although, "the main factor in the formation of bedded accumulations is local deformation of strata (folds or faults)," Brod's sub-group B, *Screened Accumulations*, includes fault traps as well as those "stratigraphically screened by an unconformity" and those *lithologically screened*. He sketched only the case of a truncated reservoir rock with the overlying sequence in the very improbable state of parallelism with the plane of unconformity. The pronounced angular discordance shown presumably would have necessitated tilting and onlap of the later beds. Here he might have expanded his concept of "stratigraphic screening" to show onlapping sands

[7] C. W. Sanders, "Stratigraphic Type Oil Fields and Proposed New Classification of Reservoir Traps" (discussion), *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27 (1943), pp. 538–50.

[8] *Ibid.*, p. 549.

[9] I. O. Brod, "Geological Terminology in Classification of Oil and Gas Accumulations," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29 (1945), pp. 1738–55.

wedging out against the unconformity. While indifference to the mode of origin of such obscurely related types of trap may be academically justified or even helpful in visualizing reservoir performance, Brod's classification does not seem particularly applicable to oil-finding.

Pirson[10] approached the classification of reservoirs from a genetic and morphological viewpoint, setting out (I) Petrologic (stratigraphic) traps, (II) Petrologic-structural traps, and (III) Structural traps. In his concept of convergence, he grouped onlap reservoirs under *petrologic traps* as illustrated in his reproduced diagram (Fig. 1), which suggests that an onlapping porous unit may thin out without encountering the regional unconformity or being involved in subsequent

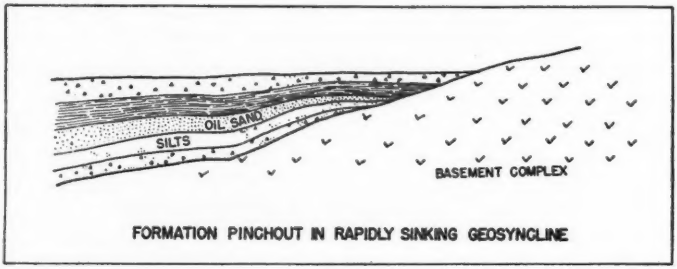


FIG. 1.—Pirson's reproduced diagram suggests an improbable case of convergence in which thinning is not due to truncation or onlap.

diastems. This popular idea is opposed by the writers who regard most cases of onlap as due to loss of beds from the base up in contact with an unconformity.

One of the most thoughtful recent efforts at classifying petroleum reservoirs was undertaken by Wilhelm.[11] In the general class, *Pinch-Out Trap Reservoirs*, he recognized *depositional* and *truncated pinch-outs* (by which he meant to differentiate loss of section due to non-deposition from that due to erosion), and thirdly, *overlap pinch-outs*. It would require exceptional conditions to accomplish loss of section merely because of the unavailability of sediments without the occurrence of enough uplift to involve erosion or off-lap. Of course, it is possible that convergence may occur on a regional scale which does not permit the recognition of specific hiatuses. Such convergence, however, is typically developed at an exceedingly minor rate. For example, the Viola (Ordovician) limestone thins about 400 feet in 180 miles from the Arbuckle Mountains northward to the Kansas-Oklahoma boundary (approximately 2.2 feet per mile). The Upper

[10] Sylvain J. Pirson, "Genetic and Morphologic Classification of Reservoirs," *Oil Weekly*, Vol. 118, No. 2 (June 18, 1945), p. 54.

[11] O. Wilhelm, "Classification of Petroleum Reservoirs," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29 (1945), pp. 1537–80.

Pennsylvanian rocks of the Anadarko basin converge at a greater rate, but there is much evidence that the deposition was oscillatory and actually involved local removal of sediments. In other words, it is difficult to visualize non-deposition on an areal scale great enough to justify applying the term "unconformity" where neither tilting nor differential erosion occurs either above or below sea-level.

As for Wilhelm's description of *overlap pinch-out reservoirs*, these evidently were to apply only to basal clastics essentially parallel with the unconformity and not to wedging-out due to convergence between the plane of deposition and the tilted unconformity. He states:[12]

> Reservoirs of this type are found in porous conglomeratic material on regional unconformities or at the base of marine overlaps over a basement complex.

## ANALYSIS OF CONVERGENCE RELATIONSHIPS

Although there are few conceivable varieties of stratigraphic traps that could have originated without the influence of structural movement, there seems a currently popular but unreasonable attitude to stress the *structural* factors involved by way of criticizing applications of the term "stratigraphic trap"; instead we should emphasize the stratigraphic attributes that permit distinguishing these from purely structural traps. Evidently the geologic processes capable of creating stratigraphic traps are: (1) depositional facies changes in porosity related to lateral differences in marine environment, (2) structural movements (tilting) requiring the deposition of offlap or, subsequently, permitting onlap deposits, and (3) tilting and differential erosion that produce truncation. While it is maintained here that the principal components of stratigraphic convergence are the combined loss of section due to truncation and onlap, it is necessary to consider the conditions under which offlap deposition and typically non-convergent sedimentary facies changes may enter into convergence problems. In the first case, one realizes that offlap clastics may be deposited by a receding sea as beach and near-shore sands are redistributed basinward. The resultant deposits should thicken seaward where deposition would proceed long after the shoreward areas were exposed. However, as the offlap deposits become exposed they are eroded along with the subsequent truncation of older beds. Even the residual detritus that may mantle this exposed and eroded surface would probably be reworked and interbedded with later onlap deposits. Only in the least affected basinward areas, having received the finer-grained equivalents of the receding beach sands, should an offlap sequence be preserved and here, in the absence of an unconformity, it would be most difficult to recognize. On the other hand, if offlapping sands are not deeply eroded or reworked by later seas, as in the case of deltaic Devonian sands in western Pennsylvania, there are possibilities of finding porous producing sands.

A proper study of a particular stratigraphic-trap problem should entail con-

[12] *Ibid.* p. 1568.

sideration of grain size, sorting, and origin of sediments indicative of depositional environment and other sedimentary factors affecting the areal distribution of porous reservoir material. This investigation is necessary even though the oil objective in question may be trapped by truncation or onlap. In the first case it is quite possible that when all the prerequisites for differential erosion and the local preservation of an oil objective are realized, still, porosity may be poor because of pre-truncation environmental factors. In other words, there need be no relation between the strike of early facies development and the trend of the subsequently truncated stratigraphic units (Fig. 2). There is also likelihood that onlap deposition will be influenced by purely environmental factors because it is

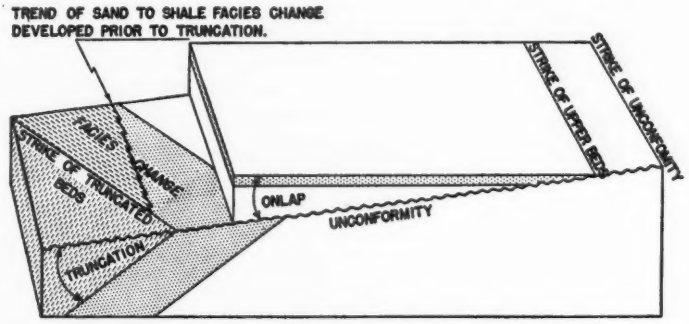


FIG. 2.—Relations between strike of onlapping beds, truncated beds, and direction of pre-unconformity facies change.

associated with rather special strand or near-shore conditions of deposition. There are several shore-line factors such as proximity to fluvial clastics, the sorting influence of littoral currents, and other irregularities in the source of clastics that are quite capable of locally creating porous sands in time-stratigraphic equivalence to impervious shale bodies.

Although the concept that stratigraphic convergence is accomplished primarily by means of truncation and onlap may be more generally appreciated than is apparent in the literature, the mathematical relationships between these two and the structural attitude of the intervening unconformity are not generally understood. Reference to Figure 3 shows that three variables are involved: (1) the dip of the unconformity, (2) the dip of the eroded beds beneath the unconformity, and (3) the dip of the overlapping beds above. These three variables determine two additional parameters, *truncation and onlap*. It is evident that the rate of onlap, for example, between two wells must be the difference in dip between the unconformity and the upper beds and that the amount of truncation is equal to the dip of the lower beds minus the rate of the dip of the unconformity. These relationships may be formulated, by use of the following symbols (Fig. 3).

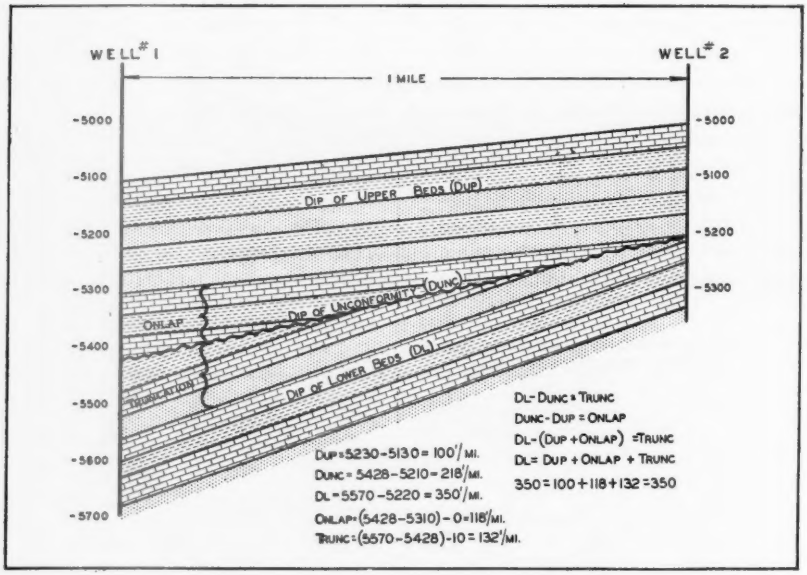
WELL # 1
WELL # 2
1 MILE
-5000
-5100
-5200
-5300
-5400
-5500
-5600
-5700
DIP OF UPPER BEDS (DUP)
DIP OF UNCONFORMITY (DUNC)
DIP OF LOWER BEDS (DL)
ONLAP
TRUNCATION
DUP = 5230 - 5130 = 100'/MI.
DUNC = 5428 - 5210 = 218'/MI.
DL = 5570 - 5220 = 350'/MI.
ONLAP = (5428 - 5310) - 0 = 118'/MI.
TRUNC = (5570 - 5428) - 10 = 132'/MI.
DL = DUNC + TRUNC
DUNC = DUP + ONLAP
DL = (DUP + ONLAP) + TRUNC
DL = DUP + ONLAP + TRUNC
350 = 100 + 118 + 132 = 350

FIG. 3.—Derivation and illustration of convergence formulae.

Dunc = Dip of Unconformity in feet per mile
Dup = Dip of Upper Beds in feet per mile
$D_L$ = Dip of Lower Beds in feet per mile
On = Rate of Onlap in feet per mile
Trunc = Rate of Truncation in feet per mile

$$\text{On} = \text{Dunc} - \text{Dup} \quad (1)$$

$$\text{Trunc} = D_L - \text{Dunc} \quad (2)$$

Transposing:

$$(1)\ \text{Dunc} = \text{Dup} + \text{On} \quad (3)$$

Tranposing:

$$(2)\ \text{Dunc} = D_L - \text{Trunc} \quad (4)$$

Now equating (3) and (4):

$$\text{Dup} + \text{On} = D_L - \text{Trunc} \quad (5)$$

This equation may be solved for any one of the four unknowns, for example:

$$\text{Dup} = D_L - \text{Trunc} - \text{On}$$

$$D_L = \text{Dup} + \text{Trunc} + \text{On}$$

$$\text{On} = D_L - \text{Dup} - \text{Trunc}$$

$$\text{Trunc} = D_L - \text{Dup} - \text{On}$$

## CONVERGENCE FORMULAE APPLIED

Such mathematical expressions may be applied to predicting the local presence or absence of onlapping or truncated oil objectives and the intervention of structural anomalies, especially faults. The first application has been useful in predetermining the areal distribution of the onlapping Deese sands that wedge out upon the early Pennsylvanian unconformity of the Pauls Valley uplift in Garvin County, Oklahoma. This technique followed the realization that the Deese and later Pennsylvanian sediments lapped out upon the truncated older rocks with

loss of section almost entirely from the base of the transgressing sequence so that a particular sand unit wedged out in contact with the unconformity at a rate equal to the difference in dip between these two surfaces. In other words, the sand beds, being deposited essentially parallel with sea-level, had to wedge out upon the unconformity whose inclined surface necessitated onlap.

Thus it was observed that the producing Deese sands were, in no sense, residual or reworked detritus merely blanketing the unconformity but were deposited intermittently between finer-grained clastics in approximate parallelism with sea-level by an oscillatory advance of the sea. One would expect (and it can be demonstrated) that there should be a critical *minimum* thickness of the onlapping sequence at which a particular sand wedges out. Further, it was realized that the porous sands graded basinward to shales so that an average *maximum* interval marked the sand to shale facies change thereby limiting porosity basinward. Thus, isopachs of the Deese thickness made it possible to determine approximately the updip and offshore limits of Deese sand porosity.

The second application of these mathematical expressions of the relationships of the dip above and below the unconformity concerns the mapping of belts of truncation, problems of paleogeology, the delineation of the regional and local fault pattern and, in fact, the gathering of the most important evidence bearing on the dates of regional orogenic movements. Correlations between scattered wells in an area of truncation will show data regarding the dip of unconformity and that of the lower strata so that the latter may be projected into the plane of unconformity to reveal successively truncated stratigraphic units.

The presence, and eventually, the pattern of faulting may be revealed by constructing paleogeologic maps and by noting discrepancies in the magnitude of truncation where the rate of onlap is more or less constant. Thus, if abnormal truncation occurs, due to local warping or faulting, the rate of truncation is affected and the specific units normally to be expected do not appear beneath the unconformity.

In Figure 4 the formula for truncation is employed to detect abnormalities suggestive of structure although the technique would be less applicable where rejuvenated faulting affected the *assumed* constancy of the rate of onlap. As mentioned earlier, recognition is being given the abundance of stratigraphic traps in the Anadarko basin of western Oklahoma. Some of these afford interesting examples of the convergence problems under discussion. For instance, the West Edmond oil field furnishes detailed and varied aspects of a truncated reservoir trap. In this area there are two prominent unconformities that affect the distribution of the producing Hunton limestone sequence. The earliest, of post-Hunton pre-Mississippian age, was associated with the Ozark uplift during which the Hunton and older Paleozoic rocks were successively truncated toward the northeast and were later overlapped by the Mississippian. The resultant northwest-trending paleo-outcrop pattern later was partly re-exposed by early Pennsylvanian orogenic movements when the Oklahoma City uplift was formed on the

southeast. As a result the Hunton and Mississippian wedge-edge trends north and south where these were truncated by the Pennsylvanian over much of the field. But where the Hunton was protected by Mississipipan rocks, its paleo-outcrop strikes northwestward, a fact not generally appreciated during efforts to extend the field northward. Also of interest are areas of locally improved porosity due to dolomitization of Hunton members as in the northeastern part of the field.

Far toward the northwest the sequence of Mississippian limestones is truncated in an arcuate pattern of paleo-outcrops bordering the Dodge City embay-

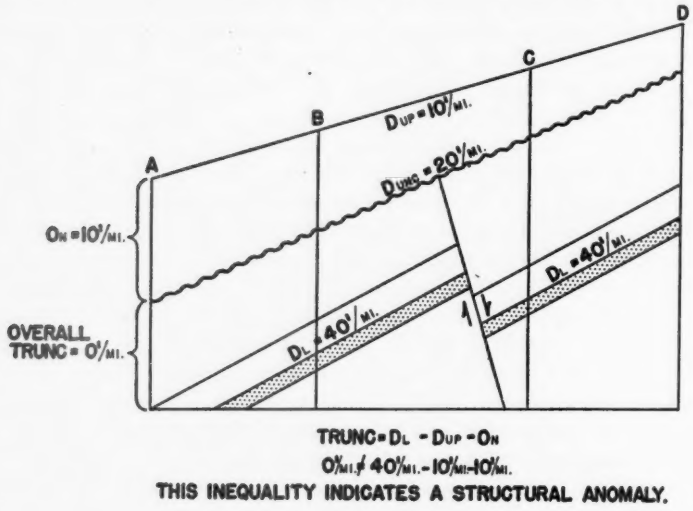


FIG. 4.—Application of convergence formula to detecting structural anomaly.

ment of the Anadarko basin. In southwestern Kansas an important producing zone is the Spergen dolomite where this beveled Mississippian formation is locally involved in a structural nose or closure. Its differentiation along the Oklahoma-Kansas boundary doubtless will be an important subsurface and seismic project of the future.

A third example of especial current interest is the problem of mapping the paleo-outcrop of the early Pennsylvanian (Springer) sands in the southeastern embayment of the Anadarko basin. Integrated seismic and subsurface data will show the proportionate components of onlap and truncation that are responsible for the tremendous rate of convergence mappable between the North Lindsay wells (with only 400 feet of lower Springer shales preserved beneath the pre-Deese unconformity) and the Stanolind Oil and Gas Company's Briscoe No. 1, now drilling 6 miles west in Sec. 4, T. 4 N., R. 5 W. Here, a 3,000-foot Springer section containing some of the upper porous sands is preserved. The position of

the sand wedge-out is solved, locally, by subtracting the rate of dip of the pre-Deese post-Springer unconformity from the rate of dip of the lower beds shown by seismic control between the Stanolind and the updip Lindsay wells.

Good examples of the interference of facies change in an onlap-type reservoir are abundant in Southwest Antioch which produces from a Pennsylvanian (Deese) sand lapping out on the Pauls Valley uplift. The Sinclair Prairie Oil Company's Ward No. 4 is a poor well because the typically porous sand *of all the direct and diagonal offset producers* had locally graded to a tight siltstone. Similarly in the Katie pool, 7 miles southwestward on the same Deese sand wedge-out, the Carter Oil Company's Emberlein No. 1, offsetting a good well, penetrated silt beds although the Deese thickness was proper for full sand development. Future drilling along this belt will doubtless reveal many barren areas where *facies changes* from sand to less porous clastics occur.

In each of these problems the importance of coordinated effort between geologist and seismologist is apparent. In fact, accelerated performance in oil-finding would certainly result if geologists were to direct shooting programs toward the study of convergence traps in areas of well control sufficient to have established the dip of the unconformity and the stratigraphic position of potential reservoir rocks. Locally, mapping of the divergent *strikes* of the older and younger rocks may aid in determining the critical dip of the unconformity, because the strike of the upper beds should closely coincide with that of the unconformity, whereas neither need parallel the strike of the lower beds (Fig. 2). In very rapid convergence where a series of reflecting horizons show distinctive enough character, the successive loss of these due to truncation may aid in locating the surface of unconformity. By pursuing this type of study one eventually recognizes the most complete stratigraphic sequence in the region. Then by noting the youngest beds beneath an unconformity and the oldest beds overlapping this surface, the orogenic movements can be dated. Finally, it is possible to comprehend the magnitude of these movements by adding up the total section lost by regional convergence.

In the long run, the most practical justification for attempting to clarify such concepts of convergence is a desire to add methods to the goal of deciphering geologic processes in the conviction that an understanding of these is essential to any geologic problem.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 11 (NOVEMBER, 1947), PP. 2030-2040, 4 FIGS.

# DIAGENESIS OF OIL-FIELD BRINES[1]

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## ABSTRACT

Analyses of oil-field waters of the United States are assembled in diagrams. From the position of the geological units in these diagrams it follows that in the development of connate water from sea water, two distinct diagenetic phases must be recognized. The first phase is the precipitation of magnesium and calcium and sulphate and carbonate, the second phase is a concentration with a gradual increase of magnesium and calcium ions. It is supposed that the first phase is due to base exchange with the clay sediment, and the second phase to a semi-permeable property of the shales during the later stages of compaction.

## INTRODUCTION

Water in the lithosphere can be derived from three sources: meteoric water, connate water, and juvenile water. It is not always easy to decide which kind of water is produced by a natural or artificial source, but the water (not the salts) which is found in marine sedimentary series at depths of many thousands of feet can hardly be of any other origin than the original sea water enclosed in the sediment during its deposition. Near the surface this water may be contaminated by meteoric water but at depths greater than 1,000 feet such contamination becomes an exception except in regions where sheet sandstones of large lateral expansion occur.

The oil industry has brought to light most of the facts about connate water, and it is to the publications of this industry we have to turn to learn about its occurrence, composition, and concentration. On the other hand, such water and brines are not restricted to oil-bearing strata but are present in every sedimentary series.

The concentration of salts in connate water varies from fresh water to a concentration of 10 times that of sea water. The concentrations lower than sea water are generally ascribed to dilution by meteoric water, but may in many cases be due to the original non-marine origin of the sediments. The younger waters of the South Sumatra basin, for instance, do not have concentrations higher than 2.4 per cent even at a depth of 4,000 feet; only the middle part of the Tertiary sediments of this region is marine; the top and bottom layers are both fresh- or brackish-water deposits. On the other hand the waters of the Rocky Mountain fields are diluted by meteoric water,[3] due to the extensive sheet sandstones of this region. Here the water circulation from mountain to plain is even made re-

[1] Manuscript received, March 12, 1947.

[2] Leiden University.

[3] J. G. Crawford, "Oil-Field Waters of Wyoming and Their Relation to Geologic Formations," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 7 (July, 1940), pp. 1214–1329.
R. C. Coffin and R. K. DeFord, "Waters of the Oil- and Gas-Bearing Formations of the Rocky Mountains," *Problems of Petroleum Geology* (1934), p. 927.

sponsible for the migration of oil and the sterility of otherwise promising structures.[4]

Besides dilution by meteoric water one must expect that during larger unconformities older sediments came again into contact with sea water which penetrated deeply into the eroded rock, particularly where porous rocks were exposed.

The remarkable salt concentration of 8–25 per cent, which is found in many oil fields, has in some places a very simple explanation: those waters which are in direct connection with salt deposits as in the Permian basin of West Texas, on the salt domes of the Gulf Coast, or in Roumania. In other places, however, no salt deposit is present in the whole stratigraphical series and an explanation for these high concentrations is far from obvious. Several hypotheses have been advanced. Mills and Wells[5] suppose that the evaporation of water in the gas may explain the high salt concentration of the Appalachian region. The volume relations between water and gas are commonly, however, not in favor of this hypothesis. At least 4 times the volume of water which is present now in these formations would have to be evaporated in a volume of gas which is many times smaller to account for a concentration of 12–15 per cent. Moreover, one may ask why the water of the California fields has not evaporated in the large volume of gas which is present in almost every structure there.

Krejci-Graf[6] advanced the theory that a change of the colloidal phase of the clay sediment allowed the adsorption of water. Moreover, most of the water itself, and not only the salts, was supposed by this author to originate as a byproduct of the disintegration of the organic content of the sediment. High concentrations of some elements as iodine or potassium, which are encountered in some oil fields (Roumania and East Java), may be derived from this source. In California the immense volume of oil, also a disintegration of the organic content of the sediment, has not given concentrated waters. When adsorption of water by the sediment is the origin of the oil-field brines the process is apparent only in the Paleozoic era, and it is not very probable that the difference between a Paleozoic shale and a Tertiary clay is due to the larger water adsorption of the former; the contrary seems more logical.

Besides the variation in concentration as compared with sea water, we find the remarkable fact in almost all connate waters that the magnesium ion and the sulphate ion have disappeared, the carbonate ion considerably decreased, so that the only salt which remains is rock salt. This change in composition has been generally ascribed to a reaction with the surrounding sediment and often to the reductive agency of the oil. The magnesium ion has entered the calcareous sediments and sulphates have been reduced to sulphides which have been precipi-

[4] E. W. Krampert, "Geological Characteristics of Producing Oil and Gas Fields in Wyoming, Colorado, and New Mexico," *Problems of Petroleum Geology* (1934), p. 719.

[5] R. van A. Mills and R. C. Wells, "The Evaporation and Concentration of Waters Associated with Petroleum and Natural Gas," *U. S. Geol. Survey Bull. 693* (1919).

[6] Karl Krejci-Graf, "Geochemie der Erdöllagerstätten," *Abh. Prakt. Geol.*, Bd. 20 (1930).

tated for instance as pyrite in the sediment. The reduction in the presence of carbon or carbon dioxide is difficult to admit, however, because a considerable amount of energy is needed for this process. In order to avoid this difficulty, it is often supposed that the reduction is a biochemical process fostered by anaerobic bacteria.[7] Recently even other sources of this energy have been proposed and it seems probable that sulphate reduction takes place to some extent.

This brief summary of the current facts and theories about the curious oil-field waters is probably sufficient to show that the different explanations are inadequate. We will have to assemble the facts from different countries and try to find some general features which might show us the way.

## ANALYSES

The water analyses used in this paper were assembled from different sources.

Several reasons to discard analyses have been applied when: (1) dilution by meteoric water was indicated by too shallow depth or by an obviously too high concentration of $SO_4$ and of $HCO_3$; (2) when admixture of salt due to salt deposits in the stratigraphical sequence could be suspected; and (3) when the analysis was not in an ionic balance (amount of cations and anions differing considerably).

Due to these reasons no analyses of the West Texas Permian basin, Roumania, Gulf Coast, and the Rocky Mountains could be used. Most of the analyses from the United States have been derived from the series of articles in *Problems of Petroleum Geology*,[8] and in particular those from Kansas, mostly from the paper by Schoewe.[9] The analyses from Sumatra are derived from the unpublished archives of the Shell in the Hague; those from the Van field from a paper by Liddle;[10] and some of the California analyses from various field descriptions. All the analyses have been recalculated, if this was not done previously, to reaction value percentages according to the method of Palmer.[11]

These analyses are plotted on three diagrams: Figure 1 giving the composition of the dissolved salts in reaction value percentages of Na+K, Ca, and Mg; Figure 2 giving the concentration in relation to the Na values; and Figure 3, giving the relation of Ca/Mg reaction value ratio to the concentration.

The geographical units are clearly shown in the concentration diagram (Fig. 2): (1) East Sumatra younger Tertiary; (2) Woodbine sand (Cretaceous) of the Texas embayment; (3) California Tertiary; (4) Arbuckle limestone of Kansas;

[7] R. L. Ginter, "Sulphate Reduction in Deep Subsurface Waters," *Problems of Petroleum Geology* (1934), p. 907.

[8] Pp. 883–986.

[9] W. H. Schoewe, "Kansas Oil Field Brines and Their Magnesium Content," *Kansas Geol. Survey Bull. 47* (1943), pp. 37–76.

[10] R. A. Liddle, "The Van Oil Field," *Univ. Texas Bull. 3601* (1936).

[11] Chase Palmer, "The Geochemical Interpretation of Water Analyses," *U. S. Geol. Survey Bull. 479* (1911).

(5) Kansas-Oklahoma Paleozoic; (6) Mississippian of the Appalachian region; and (7) Lower Devonian of the Appalachian region.

In the composition diagram (Fig. 1) the first group has been omitted as it contains no other cations than $Na^+$, and Figure 3 is concerned only with the Kansas-Oklahoma region.

When we consider the composition diagram there are a few important fea-

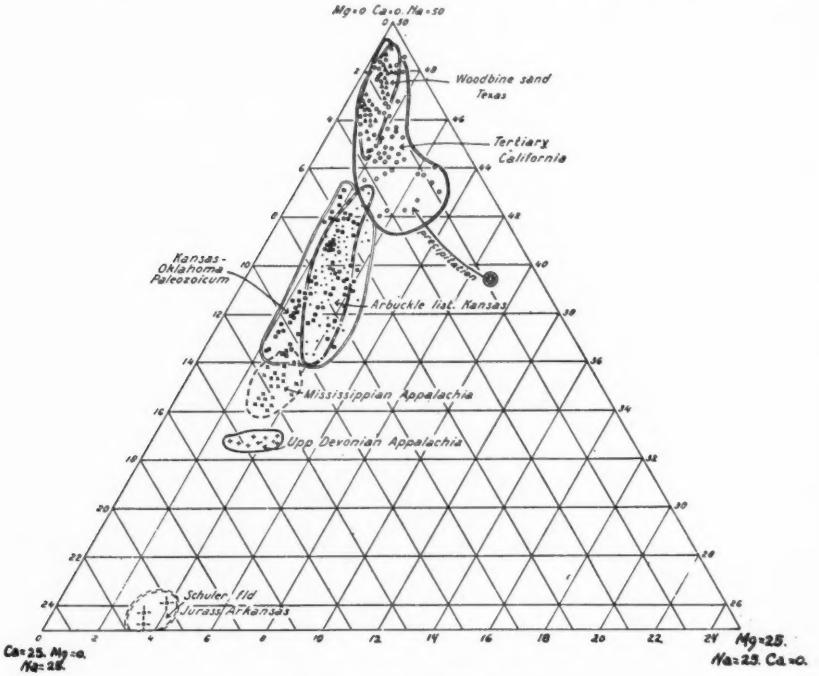


FIG. 1.—Compositi•n diagram of oil-field waters.

tures which attract our attention. First, the ratio Mg/Ca+Na varies in the narrow range between 2 and 5 per cent, except where almost all Ca has been replaced by Na. This is true for Paleozoic waters of the Mid-Continnt and the Appalachian region, and for the three analyses from the Jurassic of the Schuler field, Arkansas. In sea water $8\frac{1}{2}$ per cent (reaction value) is magnesium. Second, the field of the Tertiary California waters has a shape which curves toward the sea-water point, and when we consider this curve in detail, we see that the analyses nearest the sea-water point, having the largest content of magnesium, belong to the youngest waters of the diagram; they belong to the Pliocene of the

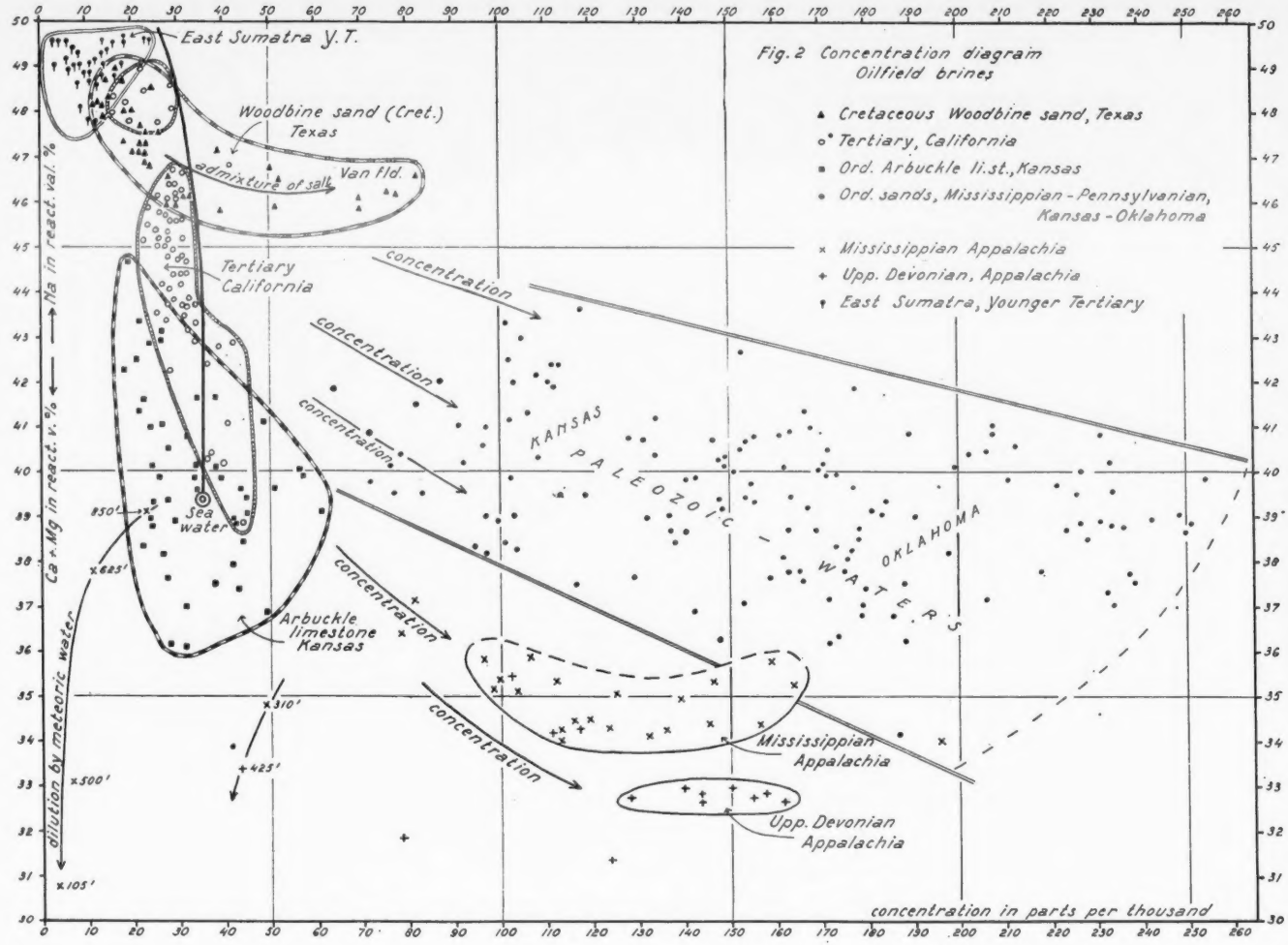


FIG. 2.—Concentration diagram of oil-field waters.

Inglewood, Rosecrans, and Potrero fields. Apparently they represent sea water in its first stage of diagenesis.

When we turn to these California waters in the concentration diagram we see that most of the analyses crowd against a line, which, starting from the sea-water point, represents the theoretical change in concentration of sea water when all other salts than NaCl are gradually extracted, thus decreasing from the original 3.5 per cent to 2.9 per cent. Apparently this is exactly what happens during the diagenesis of the connate waters; they lose their Ca and Mg as carbonates and

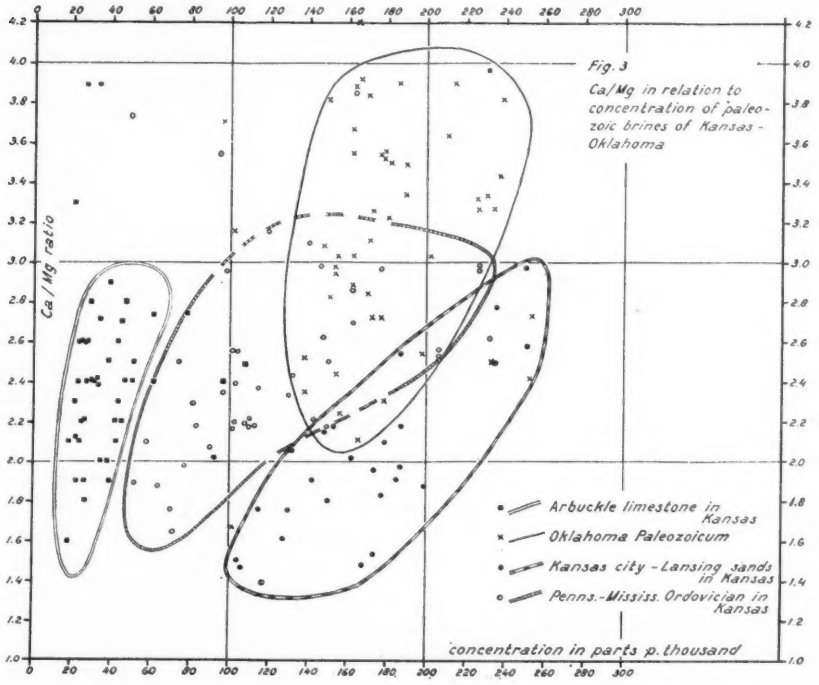
Fig. 3
Ca/Mg in relation to concentration of paleozoic brines of Kansas - Oklahoma
Ca / Mg ratio
Arbuckle limestone in Kansas
Oklahoma Paleozoicum
Kansas city - Lansing sands in Kansas
Penns.-Mississ. Ordovician in Kansas
concentration in parts p. thousand

FIG. 3.—Ca/Mg ratio relative to concentration of oil-field waters of Mid-Continent.

sulphates. A few of the analyses of this group step over this line in the lower half of the field. These analyses are the oldest waters among the whole group; they belong to the Paleogene of Elk Hills and Kettleman Hills. Apparently the process of concentration has set in already in these older Tertiary waters, a concentration which is most pronounced in the Mid-Continent and Appalachian Paleozoic waters. The fields of the Appalachian waters have rather low Na content compared with the Mid-Continent waters, and form distinct fields characterized by

FIG. 2.—Concentration diagram of oil-field waters.

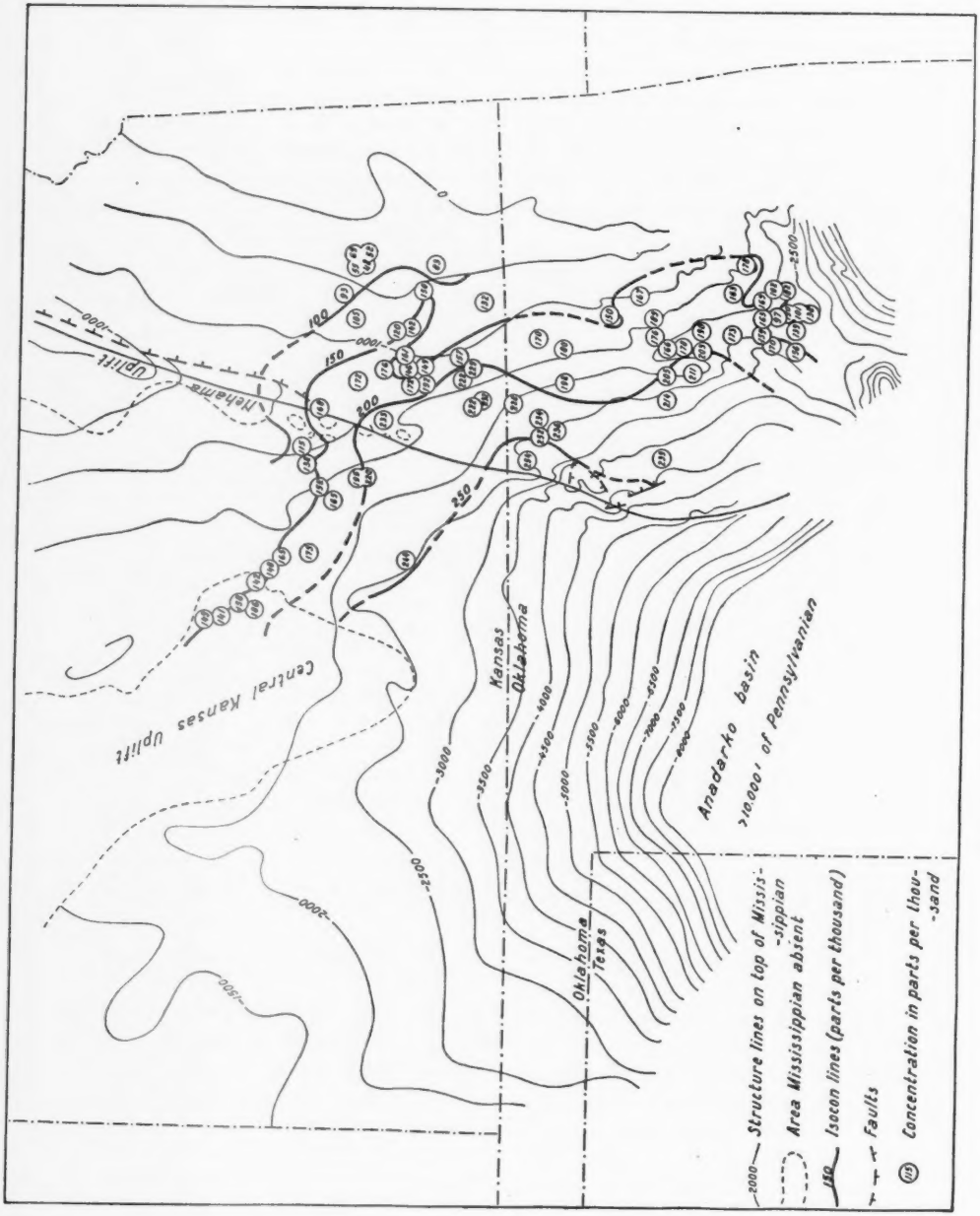


FIG. 4.—Isocon map of oil-field brines in Oklahoma-Kansas.

an increasing Ca content. This Ca content is still larger in the Jurassic in the Schuler field, Arkansas, where the Na almost equals Ca+Mg.

In the concentration diagram the Paleozoic waters of the Mid-Continent occupy a large field, which is principally limited by two slanting lines, indicating that in general the Ca percentage increases with increasing concentration. The analyses are derived from many different sands, ranging in age from Ordovician to Pennsylvanian. In general no distinction either in the composition diagram or in the concentration diagram can be made between waters from these sands; in every sand the analyses are scattered through the whole field. Important exceptions to this rule are the waters from the Arbuckle limestone in Kansas which occupy a special field round the sea-water point in the concentration diagram, but are very similar in composition to the other waters. There are, however, some smaller differences between the stratigraphic units expressed best in the Ca/Mg ratio. Therefore we have assembled in Figure 3 the Ca/Mg ratios relative to the concentration. Thus, we can recognize four fields: (1) the Arbuckle limestone field which differs only in concentration as noted before, (2) the Kansas City-Lansing waters from Kansas which occupy a distinct field as compared with (3) all the other Paleozoic waters from Kansas. Finally (4), the Oklahoma Paleozoic waters have a slightly higher Ca/Mg ratio than the Kansas waters. The Oklahoma field overlaps the two Kansas fields considerably; the latter two have only very little in common. This diagram shows, however, that the Ca/Mg ratio is altogether independent of the concentration; they are scattered irregularly over the whole field within the limits of 1.4 to 4.0 ratios and from 2 to 28 per cent concentration.

There is, however, in this region a very important correlation between the concentration and the geologic structure, which has been noticed to some extent by several authors.[12] They found that the concentration increased from the edge of the basin toward its center, and that waters from the different Ordovician beds are indistinguishable. From our compilation it appears that this is not only true for the Ordovician waters but equally true, as far as the concentration is concerned, for all Paleozoic waters, the Arbuckle limestone excluded. When we drew isocon maps first for one sand and then for the next separately it became clear that all these maps could be superimposed without any difficulty on one map and that they amplified one another. The structural significance of the combined isocon map becomes clear when it is compared with the contour map of the top of the Mississippian as has been done in Figure 4. The structure contours and the isocon lines show roughly the same general structure of the Anadarko basin, with an increase of the concentration toward the basin center. Over the Nemaha granite ridge the isocon lines show a slight bulge. Without doubt this way of superimposing the concentrations of waters of different age needs further elaboration and

FIG. 4.—Isocon map of oil-field brines in Oklahoma-Kansas.

[12] R. H. Dott and R. L. Ginter, "Iso-Con Map for Ordovician Waters," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 9 (September, 1930), pp. 1215–19.
L. C. Case, "Subsurface Water Characteristics in Oklahoma and Kansas," *Problems of Petroleum Geology* (1934), pp. 855–68.

new data may change the picture. But the available analyses, though insufficient to warrant a definite statement, very strongly suggest that the observed correlation is a reality. Provisionally we will accept it as such.

Besides these normal waters from different provinces, a few analyses have been plotted which show the dilution by meteoric water in the Berea sand of the Appalachian region; with decreasing depth they approach a fresh water.

Admixture of salt is clearly indicated by the shape of the field of the Woodbine sand. In the Van field, for instance, occur concentrations of 7–8½ per cent. Other analyses, not plotted on the diagram, from the West Texas basin have concentrations of 18 per cent and even 28 per cent. These waters are almost pure NaCl solutions, however, and therefore differ considerably from the Paleozoic brines of the Mid-Continent with the same concentration.

## INTERPRETATION

In summary, the following are the main features of the diagrammatic representation of the water analyses.

1. Each province has its particular characteristic field as well in the composition as in the concentration diagram.

2. The younger waters have a concentration somewhat less than sea water; they have lost their sodium and magnesium carbonates and sulphates.

3. Paleozoic (and Jurassic) waters from the Mid-Continent and the Appalachian region have concentrations varying from 6 to 25 per cent with a tendency of increasing Ca+Mg percentage for high concentrations.

4. The ratio Mg/Ca+Na is nearly constant (Mg approximately 3 per cent of total solids) except when Na alone constitutes more than 43 per cent of the total solids.

5. In the Anadarko basin the waters of 3,000 feet thickness of Paleozoic (except the Arbuckle limestone) are indistinguishable as to their concentration; some slight differences in Ca/Mg ratio are sometimes discernible between some provinces.

6. The concentration in this province depends on the basin structure.

7. Arbuckle limestone in Kansas has the same composition but a considerably lower concentration. In California, waters from the Los Angelos basin, Ventura basin and San Joaquin basin can not be differentiated from one another except the characteristics mentioned in item 10.

8. Almost all the subsurface waters are pure chloride solutions except when they approach fresh water when part of the Cl anion is replaced by $HCO_3$.

9. In the Californian Tertiary the youngest waters are most similar to sea water in concentration and composition; the oldest show a first tendency to concentration in the direction of the Paleozoic waters of the Mid-Continent.

10. Dilution by meteoric water can be detected through increasing percentages of the $SO_4$ and $HCO_3$ anions and decrease of the Na/Ca+Mg ratios and, of course, decreasing concentration.

11. Admixture of salt from salt deposits gives high NaCl concentrations.

Both in California and in the Anadarko basin, the waters of thousands of feet of sediment differ so little in concentration and composition that there can be no doubt that there must have been a free circulation from bottom to top. Slight local differences in composition indicate perhaps that this circulation has stopped long ago and is very slow. Moreover, the pronounced relation between the concentration and basin structure in the Anadarko basin suggests that the concentration is a function of thickness of the sediments.

Case[13] pointed out that the decrease of concentration of the Ordovician waters (Simpson and Viola sands) at the borders of the basin may be due to the dilution, but not the steady increase from 20,000 parts per million onward.

The slow and steady water circulation indicated by the common character of these Paleozoic analyses may be due to the compaction of the sediments under the ever increasing load of sediment deposition, necessitating the gradual squeezing-out of the fluid originally filling the pore space. The continuous flow of water from bottom to top in a vertical direction would have the result that original differences in composition of the connate water disappeared and that in *one* basin only *one* type of water can be found. The squeezing-out of water has been accompanied in the beginning by precipitation of all the calcium and magnesium carbonates and sulphates. It is a well known fact that the base-exchange capacity of the clay minerals favors the adsorption of the calcium and magnesium cations.[14]

The small gypsum crystals, the pyrite content, and, in some degree, perhaps the dolomitization, may all be the result of this reaction between the steady upward stream of water and the sediment. At a certain moment, however, this selective precipitation stops and some other factor determines the steady concentration of the salts in the water. Neither admixture of salt, nor evaporation of the water, nor solution of salts from the sediments, can be made responsible for this concentration phenomenon. The only direct process one can imagine is a "sieve" action of the somewhat compressed sediments, through which the compaction flow of water continues. When the sediment has acquired by compaction the property of a semi-permeable membrane, it allows the water molecules to pass through but retards the salt ions; the observed arrangement of connate water concentrations would then have found a reasonable explanation. Where the compaction has been greatest and the distance of water flow longest, the concentrations become highest, diminishing with decreasing thickness.

[13] L. C. Case, *op. cit.*
———, discussion of R. H. Dott and R. L. Ginter, *op. cit.*, p. 1218.

[14] E. McKenzie Taylor, "Papers on Base Exchange," *Jour. Inst. Petrol. Tech.*, Vol. 14 (1928), p. 725; Vol. 15 (1929), p. 207 and p. 372; Vol. 16 (1930), p. 681.
W. P. Kelley and G. F. Liebig, "Base Exchange in Relation to Composition of Clay with Special Reference to Effect of Sea Water," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18 (1934).
L. C. Case, "Base Replacement Studies of Oklahoma Shales—Critique of Taylor Hypothesis," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17 (1933), p. 66.

We have to imagine the influence of the process of compaction, therefore, in two successive stages. In the first stage the original connate sea water is squeezed out, but the Ca and Mg cations are adsorbed by the surface of clay minerals. In the second stage, when the permeability has been reduced to such extent that the clay sediment has acquired a semi-permeable property, only the water molecules are squeezed out; the salt cations are unable to pass through the much reduced average pore diameter. This average pore diameter is not the total space left between the clay minerals, because part of it is always taken up by the layers of water solutions adhering as thin films on the minerals. In these films the concentration of Ca and Mg will be much higher than that of Na, due to the base-exchange capacity of the clay. Hence, in a later phase of the compaction a portion of these water films is also squeezed out and enters the sands intercalated everywhere with the shales. This water, therefore, obtains an ever increasing percentage of Ca+Mg. The Ca and Mg which, in the first stage of compaction, were held back by the clays, re-enter the water in the later stages. The question why the ratio Mg/Ca+Na remains constant is still unsolved by this representation of the mode of concentration, but the relation may be due to some law of equilibrium between the free water and the loosely bound cations on the surface of the clay minerals.

The fact that the massive Arbuckle limestone has a considerably smaller concentration may be due to different factors, of which the most important one is probably that a massive limestone at the base of a sedimentation series is not subject to compaction. It is not compressed and no waters are squeezed through. Another factor may be that during the pre-Pennsylvanian unconformity the water originally enclosed in the Arbuckle became diluted or replaced by rainwater and was afterward partly replaced by the overlying waters, in which case the Arbuckle water should be a diluted Pennsylvanian water. The composition of the water may perhaps point to such a process.

The foregoing hypothesis on the development of oil-field brines is more in the nature of a series of suggestions than of a definite theory and is fortunately open to laboratory and field tests. Many more analyses of the Kansas-Oklahoma region are wanted to check the present isocon map, and the same principle ought to be applied on other well defined basins. It is hoped that this paper may induce someone to undertake this task.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 11 (NOVEMBER, 1947), PP. 2041-2067, 13 FIGS.

# GEOLOGICAL NOTES

## DRILLING FOR STEEPLY DIPPING OIL-PRODUCING SANDS[1]

LAWRENCE J. VITTRUP[2]
Houston, Texas

An oil well which is unique both academically and practically was recently drilled by The Texas Company on the east flank of the Saratoga salt dome of Hardin County, Texas. Because it is believed to be of general interest in the oil industry, the drilling history of this Eagle Fee well No. 4 is presented here.

In order to familiarize the reader with the general geological conditions in the vicinity of this well it may be stated that the oil is produced from a Yegua sand which pinches out on the flank of the dome and ranges in producing depth from about 5,050 to about 6,100 feet, with a dip on top of the producing sand varying between 67° and 75°. Because of this steep dip the horizontal width of the productive area is limited to about 350 feet, or to a width of one location.

Based on the data available from electrical logs and well-bore directional surveys, particularly The Texas Company's Eagle Fee well No. 3, the location for Eagle Fee No. 4 was selected so that the producing sand should have been encountered at about 5,400 feet; however, the electrical log revealed that the producing sand occurred at 4,960–4,990 (Fig. 1). Since it was believed that completion at this point would result in either a high gas-oil ratio well or a gas well, it was decided to plug back, orient a whipstock and sidetrack downdip so that the sand would be encountered between 5,400 and 5,600 feet. The gas-oil contact was estimated to be at about 5,000 feet and the water-oil contact at about 6,000 feet. To accomplish this, the original hole was first surveyed and found to be 90′ S. and 19′ W. from the surface location at a measured depth of 4,980 feet. Based on the assumed east dip of 75° on the top of the sand and a formational strike of N. 10° E., it was then recommended that the sidetracked hole be directionally drilled so that its position at 5,400 feet would be approximately 150′ S. 75° E. from the surface location. This was accomplished according to plan, but after drilling to 6,000 feet and running the electrical log, no sand was found. Therefore it was concluded that the producing sand at this location must lie at a more nearly vertical position than at any previously drilled location, and in order to find the sand it was decided to plug back and redrill for the second time. To accomplish this, an essentially straight hole was drilled to approximately 4,500 feet and then oriented S. 45° E. at approximately 4° deviation from the vertical in order to place the well bore at a depth of 5,100 feet, 50 feet east of the original hole at

[1] Published with the permission of The Texas Company. Manuscript received, August 8, 1947.

[2] Geologist, The Texas Company.

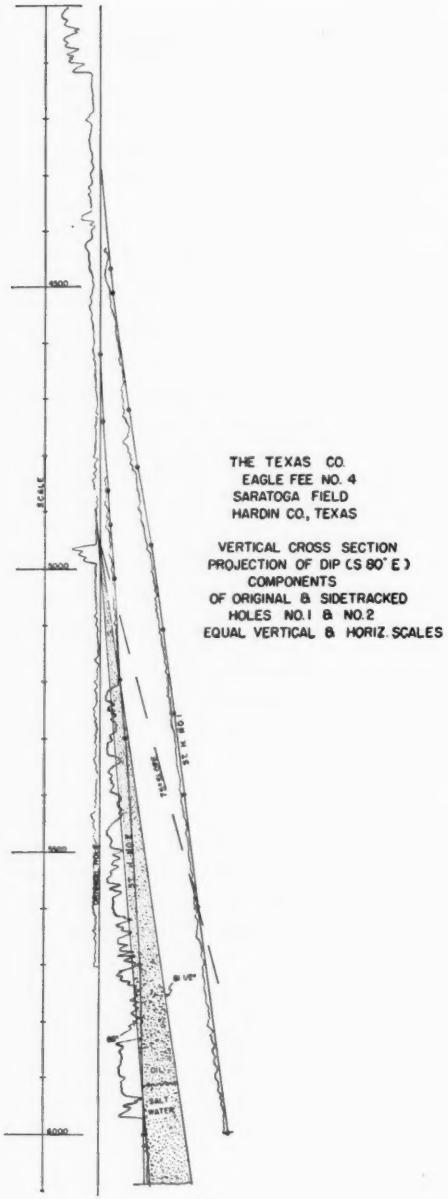
THE TEXAS CO.
EAGLE FEE NO. 4
SARATOGA FIELD
HARDIN CO., TEXAS
VERTICAL CROSS SECTION
PROJECTION OF DIP (S 80° E)
COMPONENTS
OF ORIGINAL & SIDETRACKED
HOLES NO. 1 & NO. 2
EQUAL VERTICAL & HORIZ. SCALES
SCALE
4500
5000
5500
6000
OIL
SALT WATER

FIG. 1

4,960 feet. During the course of this procedure the deviation actually reached $5\frac{1}{2}°$ and the top of the sand was found at 5,210 feet. After oil sand had been drilled and electrically logged from 5,210 to 5,407 feet, the desirability of setting another whipstock in order to stay within the plane of the sand to 6,000 feet was considered but it was decided to drill until definitely through the sand, so without further effort toward controlled directional drilling the well was drilled to 6,081 feet where the hole was off vertical only 0.5°. The electrical log revealed almost con-

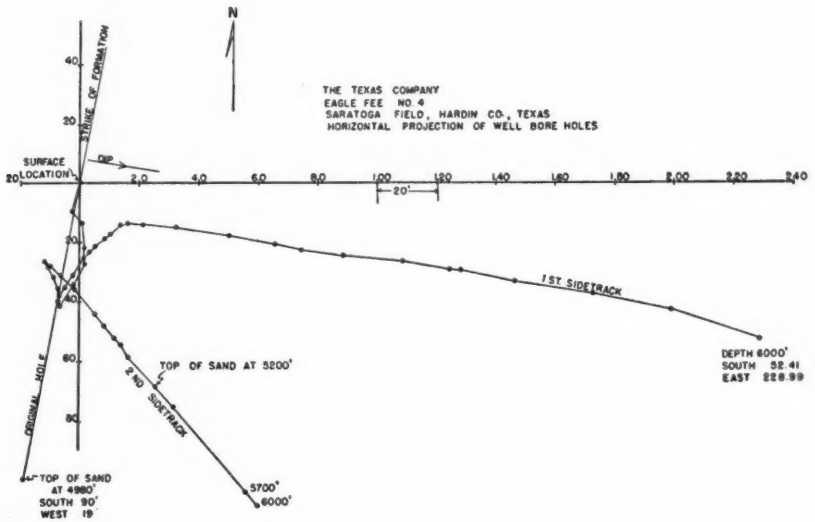


FIG. 2

tinuous oil-bearing sand from 5,210 feet to 5,950 feet and water sand to 5,975 feet.

Figure 1 shows a vertical projection of the dip (S. 80° E.) component of the three well bores to scale both horizontally and vertically. The self-potential side of each of the electrical logs is superimposed on its respective hole position in order to emphasize the actual position of the producing sand.

It will be noted from Figure 2, which is a horizontal projection of the position of each of the three well bores, that the position of the top of the 700-foot sand section in the final sidetracked hole is only 55 feet horizontally from the top of the 30-foot sand section in the original hole. All the foregoing information indicates that at this location the dip on top of the sand is approximately $81\frac{1}{2}°$ and on the base of the sand is approximately 86°.

Casing was set in the second side track hole at 6,031 feet and perforations made at 5,650–5,665 feet. Initial production on June 30, 1947, was 150 barrels

per day on 9/64-inch choke, tubing pressure 700 pounds, gas-oil ratio 819/1, gravity 39.2. It is anticipated that the exceptional conditions at this well will afford unusual opportunity for observation of reservoir behavior as affected by drainage at different structural positions.

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## TECHNIQUE FOR REPRODUCING ROCK PORE SPACE[1]

W. F. NUSS[2] AND R. L. WHITING[3]
Tulsa, Oklahoma, and College Station, Texas

### INTRODUCTION

The oil industry is vitally interested in the subject of porosity in both sandstone and limestone reservoirs. Qualitative measures of porosity are used by the geologist in guiding the location, coring, and testing of wells. The producer, operator, and engineer are guided by porosity information in acidizing, perforating, and completing wells. Porosity measurements aid the geologist and engineer in appraisal of producing properties and estimation of reserves. An understanding of the reasons for porosity development and of the various types of porosity is a necessity in modern oil-producing operations.

To facilitate studies of porosity a technique for the construction of pore-space models has been developed in the Stanolind Oil and Gas Company research department. The method allows a visible reproduction of the effective pore space. The value of these models in studies of limestone porosity has been demonstrated by Imbt and Ellison,[4] and the interest shown in the models has prompted this description of the apparatus and technique.

The procedure consists of the impregnation of core samples with a suitable plastic under high pressures. The plastic material is then polymerized at elevated temperatures and the rock material removed by leaching with acids. The remaining plastic material represents an accurate reproduction of the original effective pore space of the sample.

A similar use of plastic materials for impregnating cores prior to making thin sections has been described by several authors.[5] In all cases, however, the elimination of the rocks by leaching was not used.

[1] Manuscript received, August 21, 1947.

[2] Stanolind Oil and Gas Company, Tulsa, Oklahoma.

[3] Petroleum engineering department, A. and M. College of Texas.

[4] W. C. Imbt and S. P. Ellison, Jr., "Porosity in Limestone and Dolomite Petroleum Reservoirs," presented before American Petroleum Institute, Oklahoma, City, Oklahoma, June 7, 1946.

[5] Allen W. Waldo and S. T. Yuster, "Method of Impregnating Porous Materials to Facilitate Pore Studies," *Bull. Amer. Assoc Petrol. Geol.*, Vol. 21, No. 2 (February, 1937), pp. 259–67.
Clarence S. Ross, "A Method of Preparing Thin Sections of Friable Rock," *Amer. Jour. Sci.*, 5th Ser., Vol., 7 (1924), pp. 483–85.
Max Leggette, "The Preparation of Thin Sections of Friable Rock," *Jour. Geol.*, Vol. 36, No. 6 (August–September, 1928), pp. 249–57.
Glenn Burgener, *Pennsylvania State College Min. Indus. Exper. Bull. 12* (1933), pp. 169–70.

PROCEDURE

*Preparing sample.*—Core samples to be impregnated are first thoroughly cleaned by extraction with a benzol-carbon tetrachloride mixture for 24 hours or until fresh liquid remains clear. After drying at 212°F. for 6 hours, each core is placed in a wire frame (Fig. 1) which is intended to hold it free of the sides of the impregnation chamber (Fig. 2). The inside walls of this chamber are bored to a smooth finish to allow easy removal of the polymerized plastic, and $\frac{1}{8}$-inch steel tubing connections are made through the caps at each end (Fig. 3). One line leads to a vacuum pump and the other to a chamber of the plastic material.

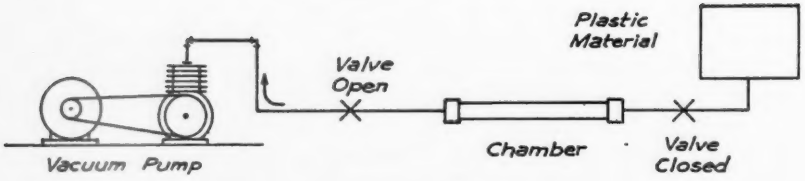
FIG. 1.—Core samples in wire frame before impregnation.

FIG. 2.—Pressure chamber.

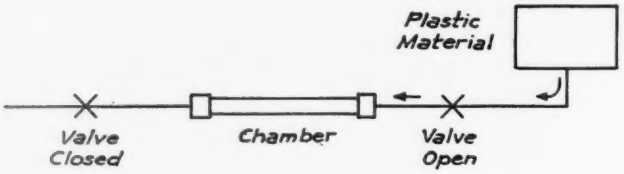
*Impregnating core.*—When the core samples have been prepared and placed in position, the chamber is sealed and evacuated. After 30 minutes a valve is opened and the liquid plastic material is forced into the chamber under atmospheric pressure. The line leading to the vacuum pump is closed when the chamber has been filled with plastic, and pressure is applied to the system with a hydraulic pump, using a heavy oil. The four steps of this process are shown in Figure 3.

It was found that best penetration of the pore spaces could be obtained by keeping the system under high pressure over a 24-hour period at a temperature below that required to polymerize the plastic material, before beginning the polymerization.

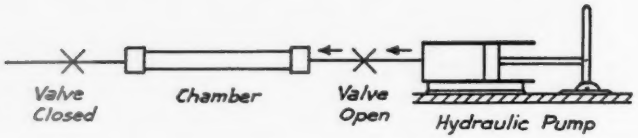
*Types of plastic material.*—Catalin, a phenol-formaldehyde resin, was used in obtaining the pore reproduction of most of the samples. Polymerization of catalin is accomplished without a catalyst in 60–70 hours at 165°F. This material is very viscous at room temperatures, becoming more fluid as the temperature is increased. The chamber was therefore kept about 150°F. during impregnation.



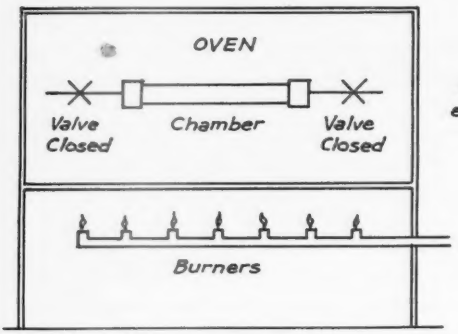

Step 1
Chamber containing cores is evacuated




Step 2
Plastic material is forced into chamber
by atmospheric pressure




Step 3
Fluid Pressure is applied on the chamber




Step 4
Plastic is polymerized at
elevated temperature in oven

FIG. 3

Pressures up to 10,000 pounds per square inch were required for the impregnation of low-permeability cores (0.05–1.0 millidarcy).

Two methacrylate plastics were tested which polymerized in 4–6 hours at

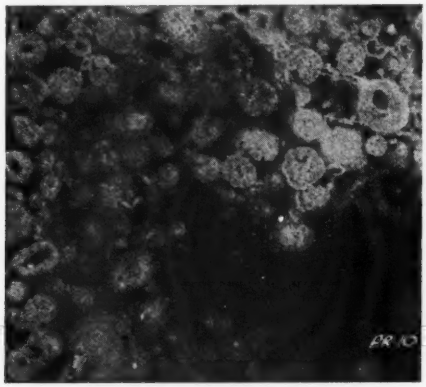


FIG. 4.—Cast of porosity, Hunton limestone (Devonian), West Edmond field, Oklahoma. Porosity 6.7 per cent, permeability 2.5 millidarcys. Porosity developed by solution of oölites.

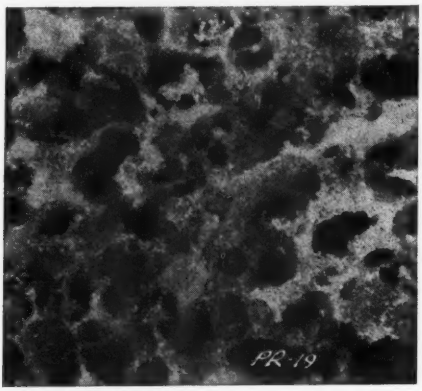



FIG. 5.—Devonian limestone, South Fullerton field, Texas. Porosity 11.2 per cent, permeability 28 millidarcys. Porosity around oölites.

195°F. with a peroxide catalyst. These were much easier to handle since it was possible to make the impregnations at room temperatures. Plastic of this type shrinks during polymerization, and acidizing the core may destroy very fine parts of the cast. One thousand p.s.i. were found to be sufficient impregnation pressure for these plastics even in low permeability.

*Leaching sample.*—After the samples are impregnated with the plastic they

are cut into wafers 3/16-inch thick, by use of a diamond saw. The wafers are then placed in very dilute hydrochloric acid to leach the rock. This is a delicate process in that the reaction rate of the hydrochloric acid with the rock must be slow to prevent breaking the finer part of the cast. After this operation, more

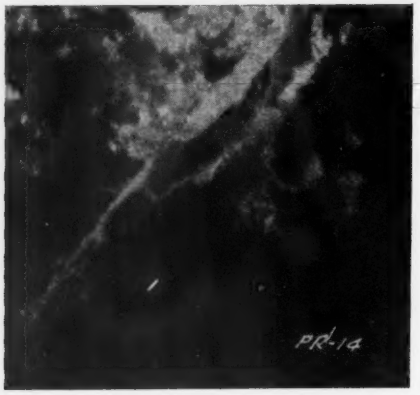



FIG. 6.—Devonian limestone, South Fullerton field, Texas. Porosity 6.0 per cent, permeability 3.2 millidarcys. Fracture porosity, enlarged by solution.

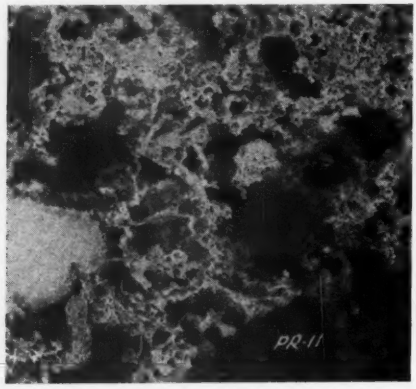



FIG. 7.—San Andres limestone (Permian), Goldsmith field, Texas. Porosity 7.0 per cent, permeability 3.2 millidarcys. Recrystallized dolomite developed by solution.

concentrated hydrochloric acid is used and finally hydrofluoric acid. Some core samples have been found to contain quantities of gypsum and silica which are not removed by acidizing with hydrofluoric acid.

Following the leaching process, each plastic model is washed carefully with distilled water. Casts have been made of core samples of permeability less than

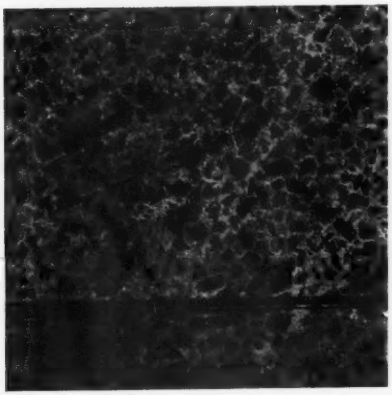


FIG. 8.—Woodbine sand, East Texas field. Porosity 25 per cent, permeability 2,100 millidarcys. Medium-grain sand with little cementing material present.

0.05 millidarcy and porosity 0.5 per cent. Typical examples of casts of various porosity types are shown in Figures 4–8 (magnification 10X). In each of these plates the light-colored material is the plastic, representing the pore spaces, the dark voids representing the original rock which are removed by acids.

## CONCLUSIONS

A practical method of reproducing rock pore space in visible form has been developed.

Casts of the porosity of Permian and Devonian reservoirs of West Texas, the Hunton of Oklahoma, the Arbuckle of Kansas, and the Woodbine of East Texas have demonstrated the usefulness and practicability of plastic models in the study of petroleum-reservoir permeability. Full-color pictures and slides of the models have been used successfully for demonstration of continuity in limestone reservoirs.

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# CROWVILLE DOME, FRANKLIN PARISH, LOUISIANA[1]

CARL L. BRYAN[2] AND WALTER F. HAMILTON[3]
Shreveport, Louisiana

The presence of a new salt dome in the northeast Louisiana area was established by drilling of the Gulf Refining Company's George Washington well No. 1-A, located 1,092 feet north and 659 feet east of the southwest corner of Sec. 11,

[1] Manuscript received, August 20, 1947. Published with permission of the Gulf Refining Company.

[2] Geophysicist, Gulf Refining Company.

[3] Geologist, Gulf Refining Company.

T. 15 N., R. 8 E., Franklin Parish, Louisiana. The dome, herein referred to as the Crowville dome, is about 4 miles northwest of the town of Crowville.

The Crowville dome was mapped as a gravity anomaly during the course of a reconnaissance gravimetric survey by the Gulf Research and Development Company in 1938, and was further investigated by a detailed gravimetric survey in 1942. The same company completed a refraction-seismograph survey of the dome in early 1946.

The Gulf Refining Company's George Washington well No. 1-A was completed on March 11, 1947, after which the rig was moved south-southwest a distance of 1,100 feet at which location the George Washington well No. 2-A was drilled to completion on April 9, 1947. Neither well reached the salt mass. A comparison of the stratigraphic sections penetrated by these two wells is here tabulated. Depths in feet are referred to the derrick floor.

| | *Gulf Refining Co. Geo. Washington 1-A Sec. 11, T. 15 N., R. 8 E.* | *Gulf Refining Co. Geo. Washington 2-A Sec. 11, T. 15 N., R. 8 E.* |
|---|---|---|
| Elevation of derrick floor | 84 | 84 |
| Base Quaternary | 179 | 187 |
| Top Cockfield | Not present | 187 |
| Top Cook Mountain | Not present | 279 |
| Top Sparta | 179 | 439 |
| Top Cane River | 313 | 1,054 |
| Top Winona | 463 | 1,194 |
| Top Wilcox | Not present | 1,237 |
| Top Midway | Not present | 1,818 |
| Top Clayton | Not present | 2,075 |
| Top Monroe gas rock | Not present | 2,088 |
| Top Austin | Not present | 2,109 |
| Top Tuscaloosa | Not present | 2,347 |
| Upper Cretaceous/Lower Cretaceous Contact (Tuscaloosa on Paluxy) | Not present | 2,432 |
| Top limestone cap rock | 572 | Not present |
| Total depth (in limestone cap rock) | 911 | — |
| Top anhydrite cap rock | Not penetrated | 2,977 |
| Total depth (in anhydrite cap rock) | — | 3,129 |

## NATIONAL COLLECTIONS OF FORAMINIFERA[1]

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Washington, D. C.

### INTRODUCTION

So many oil geologists and paleontologists have contributed directly or indirectly to the growth of the national collections of Foraminifera that a report on

[1] Manuscript received, August 21, 1947. Published by permission of the secretary of the Smithsonian Institution, and of the director of the United States Geological Survey.

[2] United States Geological Survey.

the new facilities in the National Museum for preserving the collections is due the profession.

In this brief report the character and significance of the collections and the policies for their preservation and use are outlined.

### COMPOSITION OF COLLECTIONS

The national collections of Foraminifera consist of (1) the general collection of Paleozoic to Recent faunas, (2) the T. Wayland Vaughan collection of Mesozoic and Cenozoic larger Foraminifera, and (3) the Joseph A. Cushman collection at the Cushman Laboratory for Foraminiferal Research at Sharon, Massachusetts.

The Cushman collection consists of an unusually large proportion of the genera and species of the smaller Foraminifera and of faunas that represent, so far as known, the entire range of the Foraminifera in geologic time. The Cushman collection has been assembled from many sources. During the many years that Cushman was a paleontologist on the United States Geological Survey—much of the time working partly or entirely on his own resources—he cooperated closely with the United States National Museum and received numerous Recent and fossil collections from those institutions. These formed the main basis for an unparalleled number of officially and privately published papers and monographs on the Foraminifera. In addition to these sources he obtained by purchase, exchange, or by deposition from other specialists a great number of significant collections from all parts of the world. As the leading contributor to the scientific foundations that made Foraminifera useful to oil geologists and as a pioneer himself in the commercial applications of micropaleontology, the Cushman Laboratory attained a world-wide fame. This reputation, together with the knowledge that Cushman has arranged for his collections to be deposited in the National Museum, has attracted numerous important depositions of type specimens in his laboratory. The cooperation of the Cushman Laboratory, the National Museum, and the Geological Survey has been so close that it has extended to conformity even on details of policy.

The Vaughan collection of Mesozoic and Cenozoic larger Foraminifera has a more restricted scope taxonomically than either of the other two parts of the national collections, but its relative size is no measure of its significance to paleontology and to oil geology in particular. Vaughan's interest in these fossils began and continued during his many years of service in the United States Geological Survey and dates from a time before these fossils were used in oil geology. He became the leading contributor to the knowledge that made these Mesozoic and Cenozoic larger Foraminifera useful in oil geology. His leadership in research and his encouraging and training of others to work in the same field led naturally to a world-wide acquaintaince with geologists and paleontologists and the assemblage of the foremost collection of these larger Foraminifera. The Vaughan collection contains the type specimens of perhaps nine-tenths of all

species of American larger Mesozoic and Cenozoic Foraminifera that have been described. It also contains numerous significant faunas from other parts of the world and representatives of perhaps all the genera of these larger Foraminifera.

The general collection at the National Museum contains foraminiferal faunas of all ages from Cambrian to Recent. It contains some large depositions, such as those of the Albatross expeditions (Recent) and Deaderick collection (Cretaceous) and many smaller, but important, sets of types from various American authors. The stratigraphic representation of the Upper Paleozoic Foraminifera is growing rapidly.

### NEW QUARTERS IN NATIONAL MUSEUM

As recently as 35 years ago the collections of Foraminifera in the National Museum were distributed among the other collections of invertebrates. At that time such an arrangement was obviously the logical one because the Foraminifera were most commonly studied only as parts of the general faunas.

As the sudden increase of scientific and economic interest in the Foraminifera resulted in a correspondingly rapid growth of the national collections, the older arrangement soon became outmoded. In 1932, with generous cooperation by the custodians of the other Museum and Survey collections, the writer began to assemble the Foraminifera and to segregate the types so that they could be preserved and used with the extreme care that such irreplaceable specimens require.

On May 2, 1946, a conference attended by J. A. Cushman, G. Arthur Cooper, Lloyd G. Henbest, J. B. Reeside, Jr., Waldo L. Schmitt, and T. Wayland Vaughan was held in the National Museum to formulate and recommend a uniform, official policy for caring for the Foraminifera. The conference unanimously recommended that (1) the national collections of Foraminifera be segregated and cared for as a single biologic unit, (2) space be provided to receive from time to time whatever parts of the Cushman collection that Cushman can spare and prepare to ship to Washington, and (3) two adjacent rooms, in addition to the storage and laboratory space already in use, in the National Museum be equipped exclusively for the Foraminifera. R. S. Bassler, head curator of geology and paleontology in the National Museum, joined in these recommendations.

To implement the last recommendation, Waldo L. Schmitt, head curator of biology in the National Museum, voluntarily yielded space and also his prerogatives on the custody of the Recent Foraminifera. His interest in promoting the welfare of the collections has placed the profession deeply in his debt.

The foregoing recommendations were addressed to Alexander Wetmore, secretary of the Smithsonian Institution, who approved them. The two rooms were prepared and the collections have recently been moved into the new quarters.

### SCOPE AND SIGNIFICANCE

The national collection comprises many thousands of faunas from various parts of the world. In stratigraphic, geographic, and biologic range and in taxonomic significance it is not surpassed by any other single collection. The type

specimens—primary and secondary—apparently exceed 16,000 specimens. If this number may not seem large to the non-paleontological oil geologists who are connected with laboratories where sample sets are numbered in tens of thousands, the following information shows the scientific proportions of this figure. These collections of types include (1) probably three-fourths of all the type specimens of the American smaller Foraminifera, (2) probably nine-tenths of those of the American Mesozoic and Cenozoic larger Foraminifera, and (3) a very large majority of the types of species from abroad that have been described in this country.

Type specimens have a special significance in paleontology and biology because they become the permanent, final court of appeal in determining the character of a species and genus or of any figured specimen of organism. A type specimen can not be replaced if lost or destroyed and forms the only real foundation and final reference in the scientific classification of plants and animals. Whereas no description and no illustration of a species or genus can be perfect, the type specimens occupy a focal position in paleontology and in the scientific fabric of commercial paleontology. Commercial paleontologists often adopt an arbitrary nomenclature for their special uses, but the knowledge that enables them to make practical use of those foraminifers is based on the scientific classification that these collections represent.

The type specimens of Foraminifera in the national collections are segregated and preserved with extreme care. It is the policy to mark and segregate these types so that they will not be confused with the less precious specimens. They are available in the depository for study by scientists for research work of a basic character and may not be used for casual study. They are treated and cared for much in the same way that the "standard meter" or very rare books are preserved. It is only by such care that the custodian fulfills his obligation to science and to the increasing number of specialists who deposit their type specimens in the National Museum.

Inasmuch as the National Museum is by organic law the official depository for the natural history specimens that are collected by the various Federal agencies, and as most of these agencies require constant use of their collections to carry on their work, the collections and the staffs of specialists that use them are generally housed in the National Museum. Such an arrangement has existed for many years between the paleontologists of the Geological Survey and the National Museum. The Survey is directly and indirectly by far the largest contributor of fossil Foraminifera to these collections. Both institutions have so many obligations in common to preserve these collections not only for their own use but for the profession that the closest kind of cooperation and uniformity of policy must be maintained.

### FUTURE SIGNIFICANCE

Though it is obviously impossible to predict the direction that research on the Foraminifera will take, the prospects are that interest in this order of organisms

will increase. No generally applicable substitute for the paleontological methods of correlation and age determination has yet been demonstrated. Prospects indicate that need for the use of Foraminifera in subsurface and submarine exploration for oil will increase.

Submarine geology is a new field that is bound to attract greatly increased interest. Progress in that field will necessarily depend on geochronology, in which Foraminifera seem certain to play a leading part. Marine paleoecology is a subject of rapidly increasing interest scientifically and economically. The Foraminifera are among the most prolific and widely distributed inhabitants of the planktonic and benthonic realms of the sea, and, as the Foraminifera are classifiable biologically in detail and reflect climatic and ecological conditions, their remains seem certain to figure prominently in research on paleoecology.

These collections in the National Museum represent the work of scientists who discovered the scientific significance of these organisms and gave the information that has made them useful in finding oil and gas. The usefulness of these organisms has not yet been fully exploited by the oil-mining industry. We have only begun to gather the information that they can give on marine paleoecology and in submarine geology.

There is no other depository in the world where nearly so many genera and species of Foraminifera are represented by type specimens. Likewise there is no other single collection in which so many of the foraminiferal faunas or formational assemblages of the world can be studied. With the growing significance of the Foraminifera in submarine geology, oceanography, paleoecology, economic marine biology, and even in the fields of stratigraphic and oil geology where their value was first proved, it is anticipated that a growing number of scientists from the United States and abroad will visit the national depository in Washington to obtain basic information for their research problems.

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## TWO RECENT WELLS IN COASTAL PLAIN OF NORTH CAROLINA[1]

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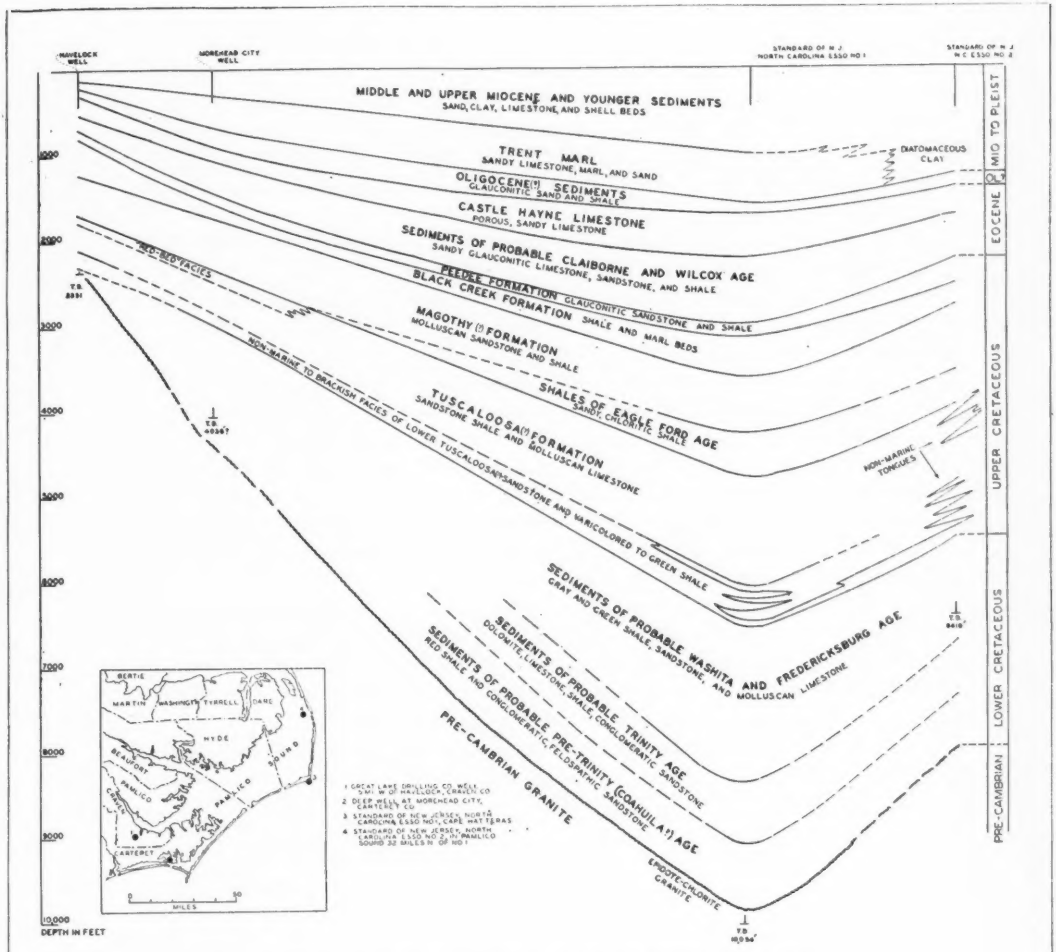
Minneapolis, Minnesota

Two wells drilled recently as stratigraphic tests in easternmost North Carolina supply important new information on the deep sedimentary rocks of the area. The Standard Oil Company's (New Jersey) North Carolina Esso No. 1,

[1] Manuscript received, August 29, 1947. Published by permission of the director of the United States Geological Survey.

[2] Department of geology and mineralogy, University of Minnesota. Sincere appreciation is expressed to J. B. Reeside, Jr., who supplied the well material from the collections of the United States Geological Survey; to K. V. White of the Standard Oil Company (New Jersey); to the Shell Oil Company, Inc.; and to R. E. Peck of the University of Missouri. Assistance in preparation of the well samples was provided by L. E. Monley and L. M. Perry.




SUBSURFACE STRATIGRAPHY OF PART OF COASTAL PLAIN OF NORTH CAROLINA

FIG. 1

completed in 1946, is located at Cape Hatteras. It encountered pre-Cambrian granite at 9,878 feet and stopped drilling at 10,054 feet. The same company's North Carolina Esso well No. 2, completed in 1947, is located in Pamlico Sound, 32 miles north of well No. 1. It stopped at 6,410 feet in the Lower Cretaceous. Considerable interest is attached to the occurrence of marine Comanche strata in both of the wells. The upper part of the interval here assigned tentatively to the Lower Cretaceous is believed to be of earlier Washita and Fredericksburg age, but the suggested Trinity and Coahuila age of the lower part is at present subject to question.

Preliminary opinions about the stratigraphic sequence and correlations in the two wells are shown in the accompanying cross section. Comparison is made with two earlier wells, located much farther updip, from which samples and paleontologic information are available. These are: a deep well drilled at Morehead City, Carteret County; and a well 5 miles west of Havelock, Craven County.

A more extensive discussion of the subject will be presented in a later article. At the present time, the writer has examined the well cuttings and cores, and has identified the species of fossil Ostracoda from the two Standard wells and the Morehead City well. The log of the Havelock well was taken principally from published records by Mansfield,[3] and from an unpublished record prepared by Doris S. Malkin, of the Shell Oil Company.[4] Certain intervals in the Havelock well were checked by the writer, whose correlations differ somewhat from those proposed by Mansfield and by Miss Malkin.

The correlations made herein are based principally on interpretation of the samples, cores, and electrical logs; on the species of fossil Ostracoda; and on such of the Foraminifera as the writer has felt qualified to determine specifically. A complete analysis of the non-ostracodal fauna will be made by specialists other than the writer, and the results included in the final report.

Brief descriptions of the sequences in the Esso No. 1 and Esso No. 2 are here given.

SUMMARIZED LOG OF STANDARD OIL COMPANY'S (NEW JERSEY) HATTERAS LIGHT WELL NO. 1 (N. C. ESSO NO. 1)

(Long. 75°31′4″ W., Lat. 35°15′0.5″ N., Cape Hatteras, Dare County, North Carolina; commenced 12-1-45, completed 7-19-46; derrick-floor elevation 24 feet; total depth 10,054 feet)

| PLEISTOCENE AND PLIOCENE SERIES | *Depth (Feet)* | *Thickness (Feet)* |
|---|---|---|
| Sand: fine- to coarse-grained, containing abundant mollusks..... | 0–180 | 180 |

[3] W. C. Mansfield, "Oil-Prospecting Well near Havelock, N. C.," *North Carolina Dept. Conserv. and Dev. Econ. Paper 58* (1927).

——, "Some Deep Wells near the Atlantic Coast in Virginia and the Carolinas," *U. S. Geol. Survey Prof. Paper 186-I* (1937).

See also: M. J. Mundorff, "Selected Well Logs in the Coastal Plain of North Carolina," *North Carolina Dept. Cons. and Dev. Inf. Cir. 3* (1944).

Olive C. Postley, "Oil and Gas Possibilities in Atlantic Coastal Plain from New Jersey to Florida, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22 (1938), pp. 799–815.

W. F. Prouty, "Atlantic Coastal Plain Floor and Continental Slope of North Carolina," *ibid.*, Vol. 30, No. 11 (1946), pp. 1917–20.

Horace G. Richards, "Subsurface Stratigraphy of Atlantic Coastal Plain between New Jersey and Georgia," *ibid.*, Vol. 29, No. 7 (1945), pp. 885–955.

[4] Supplied through courtesy of Shell Oil Company to United States Geological Survey.

| | *Depth (Feet)* | *Thickness (Feet)* |
|---|---|---|
| MIOCENE SERIES, middle and upper parts | | |
| Shell-bed; containing unconsolidated sand and with abundant Mollusca, Foraminifera, Ostracoda; in part argillaceous; conglomeratic between 260 and 290 feet; most of interval contains Duplin marl species, and may represent a thickened, downdip equivalent of that unit | 500? | 320? |
| Clay: light gray-brown, with abundant Foraminifera | 530 | 30? |
| Sand: fine- to coarse-grained, angular to subrounded, containing abundant Foraminifera; foraminiferal coquina at 710–720 feet; may represent Yorktown and St. Marys formations | 995 | 465 |
| MIOCENE SERIES, lower part | | |
| Limestone; white, porous, chalky to finely crystalline in upper part, grading to light gray more coarsely crystalline in lower part; interbedded coarse-grained, water-polished sand; abundant microfauna; probably represents Trent marl of surface exposures | 1,600 | 605 |
| OLIGOCENE (?) SERIES | | |
| Clay; buff, sandy, glauconitic, grading downward into coarse-grained glauconitic sand; Ostracoda are pre-Miocene but of problematical Oligocene or Eocene age | 1,738 | 138 |
| EOCENE SERIES | | |
| CASTLE HAYNE MARL | | |
| Limestone; white, recrystallized, fairly porous, wth drusy cavities; sparsely glauconitic, slightly sandy in upper part, becoming more sandy downward; fossils are poorly preserved | 2,220? | 482? |
| CLAIBORNE AND WILCOX (?) | | |
| Limestone; white, porous, abundantly glauconitic; and interbedded fine to medium-grained, soft, partly calcareou sandstone in units up to 50 feet | 2,870 | 650 |
| Marl and shale; light gray, soft, slightly glauconitic, sparingly fossiliferous; of questionable age | 3,034 | 164 |
| UPPER CRETACEOUS SERIES | | |
| PEEDEE FORMATION | | |
| Sandstone; white, fine-grained, porous, calcareous, glauconitic; interbedded with soft white chalk, and light gray marl | 3,104 | 70 |
| Chalk; light gray and white, slightly glauconitic; interbedded with light gray marl | 3,147 | 43 |
| BLACK CREEK FORMATION | | |
| Shale; light gray, soft, sandy in lower part; interbedded with gray marl; abundant Taylor species of microfossils, and *Inoceramus* prisms; occurrence of *Cythereis bicornis* Israelsky between 3,625 and 3,650 feet suggests possible Austin (Magothy) age for this part of unit | 3,660 | 513 |
| MAGOTHY (?) FORMATION | | |
| Sandstone ligh gray, fine- to coarse-grained, with grain size decreasing downward; partly calcareous, glauconitic; interbedded with gray shale; *Vaginulina texana* first appeared at 3,670–80 feet, but (see foregoing) top of Austin equivalent may be at about 3,625 feet | 4,288 | 628 |
| EAGLE FORD | | |
| Shale; light gray, sandy, micaceous, chloritic below 5,340 feet; interbedded with thin layers of fine-grained calcareous sandstone, and soft white chalk; *Bairdia alexandrina* Blake at 4,750–60 feet, and below | 4,800 | 512 |

| | *Depth (Feet)* | *Thickness (Feet)* |
|---|---|---|
| TUSCALOOSA (?) FORMATION | | |
| Sandstone; shale, and limestone, interbedded; sandstone is light gray, fine- to coarse-grained, calcareous, porous, glauconitic, with abundant oyster shells; shale is gray, micaceous, chloritic, with a little carbonaceous material; limestone is white and gray-brown, sandy, partly glauconitic and with abundant oyster shells; unit contains mixing of Upper and Lower Cretaceous ostracode species that, in combination with other data, suggests complete conformity between Upper and Lower Cretaceous in vicinity | 6,170 | 1,370 |
| Shale; bright green, poorly laminated, with irregular fracture; sandstone, fine- to medium-grained, white and greenish gray, in several units 10–20 feet thick; limestone, white, oyster-bearing, in scattered thin units; interval represents sequence of interfingering marine and non-marine layers; non-marine layers contain significant ostracode faunule | 6,475 | 305 |
| Sandstone; light greenish gray and white, fine- to medium-grained, calcareous | 6,584 | 109 |
| LOWER CRETACEOUS SERIES | | |
| EARLY WASHITA AND FREDERICKSBURG | | |
| Sandstone; white, fine-grained, calcareous; interbedded with white, gray and brown limestone having gray "pseudo-oölitic" spots, and light gray-brown, fissile shale | 6,700 | 116 |
| Limestone; white and brownish, slightly porous, partly oölitic and "pseudo-oölitic"; interbedded with brownish gray, fissile shale; layers of green, brown, red, and purple shale from 6,040 to 7,010 feet | 7,015 | 315 |
| Sandstone; light gray and white, fine- to coarse-grained, partly calcareous; interbedded with thin layers of green shale and white, finely crystalline, fairly porous, partly oölitic limestone | 7,430 | 415 |
| Shale; dark gray, soft, fissile | 7,585 | 155 |
| Sandstone; light gray, fine- to medium-grained, angular, porous, partly calcareous; interbedded with dark gray fissile shale | 7,760 | 175 |
| Limestone; white, gray, and brown, dense, partly fossiliferous and oölitic; interbedded with brownish gray, fissile shale | 8,240 | 480 |
| Sandstone; light gray and white, fine- to coarse-grained, mostly angular, porous, partly feldspathic, chloritic; finely conglomeratic in lower part | 8,500 | 260 |
| TRINITY | | |
| Dolomite; light brown and gray, cavernous, coarsely crystalline, partly sandy; toward base are layers of oölitic limestone cemented by brown, coarsely crystalline dolomite | 8,590 | 90 |
| Limestone, sandstone, and shale, interbedded; limestone is gray, dense, partly sandy and congomeratic; shale is gray and green; sandstone is light gray and white, mostly conglomeratic; 10-foot layer of white *anhydrite* occurs at 8,790–8,800 feet | 8,880 | 290 |
| Shale; light gray and greenish gray, sandy | 8,980 | 100 |
| Limestone; gray and brown, dense, partly sandy and conglomeratic; interbedded with hard, dark gray shale; 10-foot layer of white, feldspathic quartz conglomeratic at 9,100–10 feet; Foraminifera identified by L. G. Henbest as related to *Choffatella* in core at 9,115–16 feet; core also contains mollusks and *Schuleridea* sp. aff. *S. pentagonalis* Swartz and Swain | 9,150 | 170 |
| PRE-TRINITY (COAHUILA?) | | |
| Sandstone; white in upper part, ferruginous and reddish below 9,475 feet, fine- to coarse-grained and conglomeratic, feldspathic; interbedded with varicolored and red, partly sandy shale; varicolored shale confined to upper part of unit, while red shale occurs below 9,475 feet; where sandstone is white, feldspar grains are typically fresh in appearance; where sandstone is reddish, feldspar is reddish and kaolinic | 9,878 | 728 |
| PRE-CAMBRIAN GRANITE | | |
| Granite; red, medium crystalline, chloritic, with epidote; upper part considerably weathered | 10,054 Total depth | |

The fossils that have been obtained from 8,500–9,350 feet are definitely Mesozoic in age, but there is uncertainty as to the precise position of the sediments. Reeside[5] identified *Ostrea*, *Alectryonia*, *Plicatula*, *Camptonectes?*, and *Brachydontes* from the core at 9,115–9,116 feet. Henbest[6] reports that the foraminifer related to *Choffatella*, found in this core, suggests Lower Cretaceous or Jurassic age. The single ostracode specimen from the same level is close to *Schuleridea pentagonalis* Swartz and Swain, which was described[7] as being confined to the Upper Jurassic Schuler formation of the northern Gulf region. Subsequently, the writer has found specimens in limestone presumably from the Lower part of the Trinity group of the subsurface of Louisiana that are similar to species of *Schuleridea*, including *S. acuminata* Swartz and Swain, and *S. pentagonalis* Swartz and Swain.

The interval from 8,500 to 9,150 feet, together with the conglomeratic sandstones and redbeds below, are here placed tentatively in the Lower Cretaceous because of their general lithologic similarity to the Trinity group and underlying Hosston formation (Coahuila series), as found in the subsurface of the northern Gulf region. The conglomeratic sandstones and redbeds below 9,150 feet seem to be conformable with, and probably gradational into, the overlying limestones and shales.

SUMMARIZED LOG OF STANDARD OIL COMPANY'S (NEW JERSEY) N. C. ESSO WELL NO. 2

(Long. 75°33′54″ W., Lat. 35°42′12″ N., Pamlico Sound, Dare County, North Carolina; commenced 1-7-47, completed 3-13-47; drive-bushing elevation 21 feet; total depth 6,410 feet)

| | *Depth (Feet)* | *Thickness (Feet)* |
|---|---|---|
| PLEISTOCENE AND PLIOCENE SERIES | | |
| Sand; fine-grained, slightly glauconitic, with a few Foraminifera; samples incomplete between surface and 100 feet and between 160 and 230 feet | 0–230? | 230? |
| MIOCENE SERIES | | |
| Sand and shell-beds; interbedded fine- to coarse-grained sand, and layers of shells; abundant Miocene microfauna; glauconitic at base | 415 | 185? |
| Limestone; light gray, porous, fragmental, coquinoid | 460 | 45 |
| Sand and shell-beds; pebbly in lower 100 feet | 800 | 340 |
| Clay; light gray, sandy, diatomaceous, abundant Foraminifera below 1,070 feet | 1,265 | 465 |
| OLIGOCENE (?) SERIES | | |
| Sand; fine- to coarse-grained, water-polished, sub-rounded; fish remains abundant in upper part; glauconitic in middle part; shaly below 1,390 feet | 1,420 | 155 |
| EOCENE SERIES | | |
| CASTLE HAYNE MARL | | |
| Limestone; white, porous, partly sandy, fossiliferous, glauconitic | 1,600 | 180 |
| Marl; light gray, soft, abundant microfossils | 1,650 | 50 |
| Limestone; white, fairly porous, glauconitic sandy | 1,730 | 80 |

[5] Written communication.

[6] Written communication.

[7] F. M. Swartz and F. M. Swain, "Ostracoda from the Upper Jurassic Cotton Valley Group of Louisiana and Arkansas," *Jour. Palaeontology*, Vol. 20, No. 4 (1946), pp. 362–73.

| | *Depth (Feet)* | *Thickness (Feet)* |
|---|---|---|
| CLAIBORNE AND WILCOX (?) | | |
| Sandstone; white, fine- to coarse-grained, calcareous, glauconitic, with layers of sandy limestone interbedded | 1,980 | 250 |
| Shale; light gray; with interbedded soft marl; white chalky limestone 2,080–2,100 feet | 2,224 | 244 |
| UPPER CRETACEOUS SERIES | | |
| PEDEE FORMATION | | |
| Sandstone; coarse-grained, very glauconitic, containing siderite nodules | 2,250 | 26 |
| Shale; light brownish gray, silty and micaceous, glauconitic | 2,525? | 275? |
| BLACK CREEK FORMATION | | |
| Shale; light gray, silty and sandy, glauconitic; top chosen at first occurrence of *Kyphopyxa christneri* (Carsey) | 2,760 | 235? |
| MAGOTHY (?) FORMATION | | |
| Sandstone; white and light gray fine- to coarse-grained and conglomeratic becoming finer-grained downward; interbedded gray shale and with many oyster shell-beds below 3,000 feet | 3,285 | 525 |
| Shale; gray, soft, with abundant oyster shells | 3,515? | 230? |
| EAGLE FORD | | |
| Shale; gray, micaceous; abundant oyster shells in lower part; unit of sandy, glauconitic limestone between 3,720 and 3,795; *Bairdia alexandrina* Blake first appears at 3,770–80 feet; upper part of unit of uncertain age | 3,890 | 375? |
| TUSCALOOSA (?) FORMATION | | |
| Sandstone and shale, interbedded; sandstone light gray and white, fine- to coarse-grained, partly conglomeratic, with grain size decreasing downward, calcareous and oyster-bearing; shale gray, sandy, micaceous, carbonaceous, fossiliferous, containing several layers of varicolored and red shale | 4,940 | 1,050 |
| Shale and sandstone, interbedded; shale green and greenish gray and varicolored, representing interfingering marine and non-marine facies; sandstone light gray and white, mostly fine-grained, calcareous, oyster-bearing; prominent 40-foot unit of sandstone at base | 5,495 | 555 |
| LOWER CRETACEOUS SERIES | | |
| EARLY WASHITA and FREDERICKSBURG | | |
| Limestone and shale in rather thick, interbedded units; limestone white, porous, apparently weathered at top grading downward into light gray and and denser limestone, partly oölitic and with mollusks; shale gray and gray-brown, fissile; anhydrite layers at 5,690–5,700 feet and 5,710–20 feet | 6,120 | 625 |
| Sandstone and shale, interbedded; sandstone light gray and white, fine-grained, porous, partly calcareous, chloritic; shale interbedded light green and gray; *Atopochara* sp. between 6,360 and 6,370 feet | 6,410 Total depth | |

## OIL CONFERENCE AT HANNOVER, GERMANY SEPTEMBER 9–11, 1947[1]

ALBERT GREGERSEN[2]
Copenhagen, Denmark

An oil conference was held at Hannover, Germany, from the 9th to the 11th of September, 1947. The last such meeting was held by the German Geological

[1] Manuscript received, September 29, 1947.

[2] Vice-president, Danish American Prospecting Company.

Society in 1943. Since that time all of Northwest Germany has been investigated with modern geophysical methods, and nearly 1,000 tests have been drilled for oil and iron ore. Over 100 geologists and geophysicists have been occupied with a scientific study of the results, but until the present time only a very few results have been made available to the public.

Through the Reichsamt für Bodenforschung, the Government agency dealing with subsurface investigations, these results have now been made available. Excellent maps covering northwestern Germany have been prepared during the past two years by this organization. Sixteen of these are already published, and eight more are to be published during the coming year, all covering the entire area of northwestern Germany in which oil possibilities exist.

The meeting at Hannover was attended by 550 geologists, geophysicists, and others interested in oil developments in Germany. A relatively small number of guests from outside of Germany were present. Among these was W. F. P. McLintock, director of the Geological Survey of Great Britain.

It was extremely interesting to see that the problems which had occupied American petroleum geologists and geophysicists had also taken on much importance in the area of northwestern Germany. This was particularly true of questions relating to permeability of oil reservoirs and the question of "Most Efficient Rate of Production," or the well known M.E.R., which occupied American petroleum engineers during the war. The extremely high rates of production which prevailed in Germany during the first year or two of the war resulted in a marked deterioration of the oil fields involved, and the data obtained from production records covering this period have made it very evident to German geologists and engineers that production must be adjusted to the most efficient rate.

The papers presented at the meeting and the discussions which followed, as well as the exploratory activity which is now taking place in Germany, indicate a very marked trend toward the exploration of inter-saltdome structures. It may well be that the favorable results which had been obtained on structures other than piercement salt domes, as for instance the Coevorden field in Holland, may be largely responsible for the increased interest in the possibility of such structures.

The German oil geologists are very much interested in obtaining publications covering developments and research outside of Germany during the war years. Particular interest was shown in the *Bulletin* of the American Association of Petroleum Geologists and the publication of the Society of Exploration Geophysicists, as well as oil-trade journals, which have not been received in Germany since 1940. The moving spirit behind the meeting was Professor A. Bentz, director of the Reichsamt für Bodenforschung, who delivered a paper on the first day, covering the search for oil in Northwest Germany from 1932 to 1947. The meeting was a credit to Professor Bentz and all of those who presented papers at the meeting. Among the guests was Professor Hans Stille of the Geological Institute of the University of Berlin, who is known to many members of the Association,

of which he is a honorary member. Professor Stille presented a very interesting paper on "The Saxonic Tectonics in the European Picture."

The papers presented evoked lively discussion, and it was interesting to observe that this meeting resembled in many respects the meetings held by American petroleum geologists. The problems were more or less the same, and the presentation of papers and the discussions which followed might well have taken place in America, the language being the only distinguishing characteristic. Professor Bentz and his co-workers are to be complimented on the very excellent meeting.

TECHNICAL PAPERS, HANNOVER OIL CONFERENCE

1. A. BENTZ, Reichsamt für Bodenforschung, Celle. Results of Geological Exploration for Oil in Northwest Germany, 1932-1947.
2. HERMAN REICH, Reichsamt für Bodenforschung, Celle. Geophysical Exploration for Oil in Northwest Germany, 1932-1947.
3. ALFRED MAYER-GÜRR, Rodewald (Krs. Reinburg Wesser). Classification of German Oi Fields from an Energy-Measuring Standpoint.
4. Discussion about Establishing a German Society for Petroleum Science.

I. Saxonic Tectonics

5. HANS STILLE, Geolog.-Paleontolog. Inst. der Universität Berlin. Saxonic Tectonics in the European Picture.
6. GERHARD RICHTER, Deutsche Geologische Landesanstalt, Berlin. Plan and Regional Position of the Saxony Basin.
7. FRANZ LOTZE, Geolog.-Paleontolog. Inst. der Universität Münster in Westfalen. Orogenic Forces in Saxonic Mountain Making.
8. ALFRED KRAISS, Deutsche Erdöl A. G., Wietze. Regional Tectonics of Schleswig-Holstein and North Hannover.
9. OTTO HEERMANN, Deutsche Vacuum Oel A.G., Celle. Tectonics of the North Rim of the Hannover Basin.
10. ARTHUR ROLL, Gew. Elwerath, Hoheneggelsen. History of the Salt Stock Development in Braunschweiger Bucht.
11. FRITZ FORCHE, Deutsche Vacuum Oel A.G., Celle. The Neustadt-Engelbosteler Saddle.
12. Discussion about the Establishment of a German Geological Society in the British Zone of Occupation.

II. Paleogeography

13. HERMANN SCHMIDT, Geolog.-Paleontolog. Inst. der Universitat Göttingen. The Grading by Facies of Fossil-Bearing Sediments.
14. FRITZ HEIDORN, Haste bei Wunstorf. The West German Zechstein and Its Insertion in the Paleogeographic Picture of the Zechstein Formation.
15. KARL HOFFMANN, Reichsamt für Bodenforschung, Celle. Paleogeography of the Lias and Dogger in Northwest Germany.
16. WOLFGANG SCHOTT, Reichsamt für Bodenforschung, Celle. Paleogeography of the Malm in Northwest Germany.
17. OTTO SEITZ, Reichsamt für Bodenforschung, Celle. Stratigraphy and Paleogeography of the Cretaceous.
18. FRANZ BETTENSTADT, Preuss. Bergwerks- und Hütten A.G., Eddesse. Paleogeography of the Tertiary Sea in Northwest Germany.

III. Geophysics

19. GUSTAV-ADOLPH SCHULZE, Geophysikal. Inst. d. Universität Göttingen. Seismic Waves from the Blasting at Helgoland.
20. THEODOR KREY, Seimos M.b.m.H., Hannover. Examples of Reflection—Seismic Results in Northwest Germany.
21. HANS CLOOS, Reichsamt für Bodenforschung, Celle. Gravity Picture of Salt Structures in Northwest Germany.
22. STEPHAN BARON VON THYSSEN-BORNEMISZA, Seismos G.m.b.H., Hannover. Gravity Instruments for Stratigraphic Research.
23. BERNDT PAUL (Schlumberger Verfahren) Wietze. Geo-Electric Schlumberger Surveys on the Surface and in Bore Holes.

24. FRANZ HALLENBACH, Reichsamt für Bodenforschung, Hannover. Physical Mineral Data: Definition and Application.

IV. Petroleum Geology

25. HERMANN DEECKE, Deutsche Erdöl A.G., Heide in Holstein. Stratigraphic Succession and Tectonics of the Rotliegend-Zechstein Salt Upthrust of Heide.

26. ROLF BEHRMANN, Deutsche Vacuum Oel A.G., Bergedorf. Geology and Stratigraphy of the Reitbrook Oil Field at Hamburg.

27. HANS WEBER, Deutsche Erdöl A.G., Wietze. Stratigraphy and Tectonics of the Thoren Oil Field.

28. HEINRICH SCHLÜTTER, Gewerkschaft Brigitta, Steimbke. The Steimbke-Rodewald Oil Field.

29. HELMUT FAHRION, Gewerkschaft Elwerath, Wesendorf, und WALTER RUHL, Deutsche Erdol A.G., Wietze. The Geology and Exploration of the Wesendorf Oil Field.

30. WILHELM KEHRER, Wintershall A.G., Celle. The Geology of the Fuhrberg Oil Field.

31. HERBERT LÖGTERS, Reichsamt für Bodenforschung, Gildehaus, and FRIEDRICH BREYER, Preuss. Bergewerks- und Hutten A.G., Eddesse. Georgsdorf, an Oil Field in Emsland.

32. OSWALD SCHMIDT, Schachtbau- und Tiefbohr Ges. m.b.H., Lingen (Emsland).

V. Petroleum Geological Methods

33. HILMAR SCHUMANN, Sedimentpetrographisches Institut der Universität Gottingen. The Shape of Rock Pores.

34. HEINRICH HILTERMANN, Reichsamt für Bodenforschung, Hannover. The Most Important Results of Micropaleontological Work in Northwest Germany.

35. ERICH BRAND, Wintershall Akt. Ges., Celle. Micropaleontological Associations in the Dogger and Valendis of Northwest Germany.

36. JOHANNES WOLBURG, Gewerkschaft Eiwerath, Benthein. The Biostratigraphy of the Wealden According to the Ostracodes and Their Use.

37. FRANZ E. HECHT, Deutsche Erdol Akt. Ges., Wietze. Principles of Micropaleontology.

38. ALBERT SCHAD, Wintershall A.G., Emlichheim (Emsland).

39. HEINZ TOBIEN, Geologisch-Paleontolog. Inst. d. Universität Freiburg im Breisgau. Distant Correlation by Schlumberger Well Records in the Tertiary.

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## SANTIAGO POOL, KERN COUNTY, CALIFORNIA[1]

GLEN W. LEDINGHAM[2]
Bakersfield, California

ABSTRACT

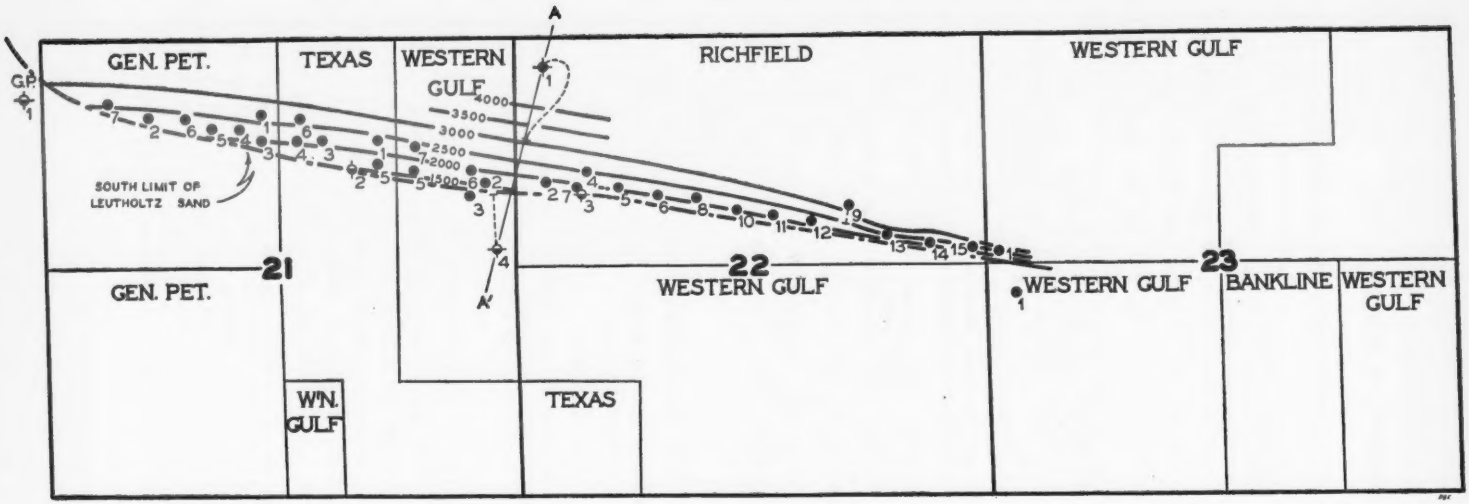
The Santiago pool is a stratigraphic oil accumulation in a large upper Miocene sand lense complicated by steep dips but very little faulting. The present length is 2 miles and it has a maximum width of 470 feet. The pool was discovered by a careful study of available subsurface information plus a generous portion of good luck.

The Santiago pool is in Secs. 21, 22, and 23, T. 11 N., R. 23 W., S. B. B. & M., Maricopa district, Kern County, California. It is on a slightly eroded alluvial fan which obscures all the surface geology in the area. The name was derived from Santiago Creek, a north-flowing intermittent stream about a mile east of the pool.

The discovery well was the Western Gulf Oil Company's I. M. Woodward U.S.L. No. 2 in the NE. ¼ of Sec. 21, T. 11 N., R. 23 W. It was drilled in July,

[1] Manuscript received, October 16, 1947. This paper is the second in a series sponsored by the A.A.P.G. Pacific Section Committee for Preliminary Reports on Discoveries, consisting of George H. Roth, William H. Thomas, and Harold H. Sullwold, Jr., chairman.

[2] Assistant chief geologist, Western Gulf Oil Company. The writer thanks the Western Gulf Oil Company for permission to publish this paper, other members of the geological department of the same company for their help in the preparation of the illustrations and text, and the numerous geologists whose helpful criticism improved the accuracy of the information herewith presented.




T11N
R23W
MDB&M.

## SANTIAGO POOL

CONTOURED ON THE TOP OF THE LEUTHOLTZ SAND

0 500 1000 2000
SCALE

FIG. 1

1945, and completed on August 1 of the same year. The producing sand was topped at 2460 feet and the well was bottomed in oil sand at 2678 feet. The discovery well was subsequently deepened to 3520 feet and bottomed in shale. The initial production of the discovery well was: 1021 B/D, 23.5°, 1.0%, 32/64" 300/400#, 120 M.C.F. Since August 1, 1945, 29 more producers and four dry holes have been drilled, developing and delineating the pool. The north, south and west productive limits have been established and development is progressing slowly eastward. The pool is now 2 miles long and has a maximum width of 470 feet.

The discovery of the Santiago pool was due to subsurface work. Numerous old wells, most of which are not shown on the map (Fig. 1), were drilled in the area. The Richfield Oil Corporation's Leutholtz-A No. 1 near the NW. corner of Sec. 22, T. 11 N., R. 23 W., found a 1300-foot sand body in the Miocene, the top few feet being poorly saturated with heavy oil. The Western Gulf Oil Company obtained acreage in the area and drilled updip from the Richfield well, making a successful discovery on the second attempt.

The stratigraphy of the pool is consistent with the rest of the Maricopa area but varies slightly from well to well. In the discovery well the following formations and zones were recognized.

| *Depth in Feet* | *Formation* |
|---|---|
| 450 | Alluvium |
| 553 | Tulare |
| 704 | San Joaquin |
| 1025 | Etchegoin |
| 2460 | Upper Miocene Brown shale |
| 3340 | Leutholtz oil sand |
| 3520 | Interbedded shale and tight oil sand |

It is possible that the Tulare-San Joaquin and San Joaquin-Etchegoin contacts are unconformable but the data are insufficient to prove this hypothesis. That there is a pronounced unconformity at the Etchegoin-Brown shale (Pliocene-Miocene) contact has been amply proved by cores. Discordance in dip varies from 10° to 30° between the two formations in wells only 300 feet apart.

The main producing zone in the Santiago pool is the Leutholtz sand. The average strike on the top of the sand is N. 80° W. and the average dip is about 70° N. There are minor variations in the strike, and the dip varies from a low of about 65° at the west end of a high of 85° at the east end of the pool. The structure so depicted on the top of the sand is an almost flat, steeply north-dipping plane. Only one significant fault has been penetrated in the productive area and that by only one well, the easternmost well in the pool. Data are insufficient to determine the correct dip and strike on this fault.

It is thought by some that the south limit of production and the south limit of the Leutholtz sand is a fault. The writer has been unable to find supporting evidence for this theory and believes that the Leutholtz sand is a large lense in the upper Miocene shale. That it pinches out or shales out in a westward direction has been proved by development. Electric-log correlations above the sand can be

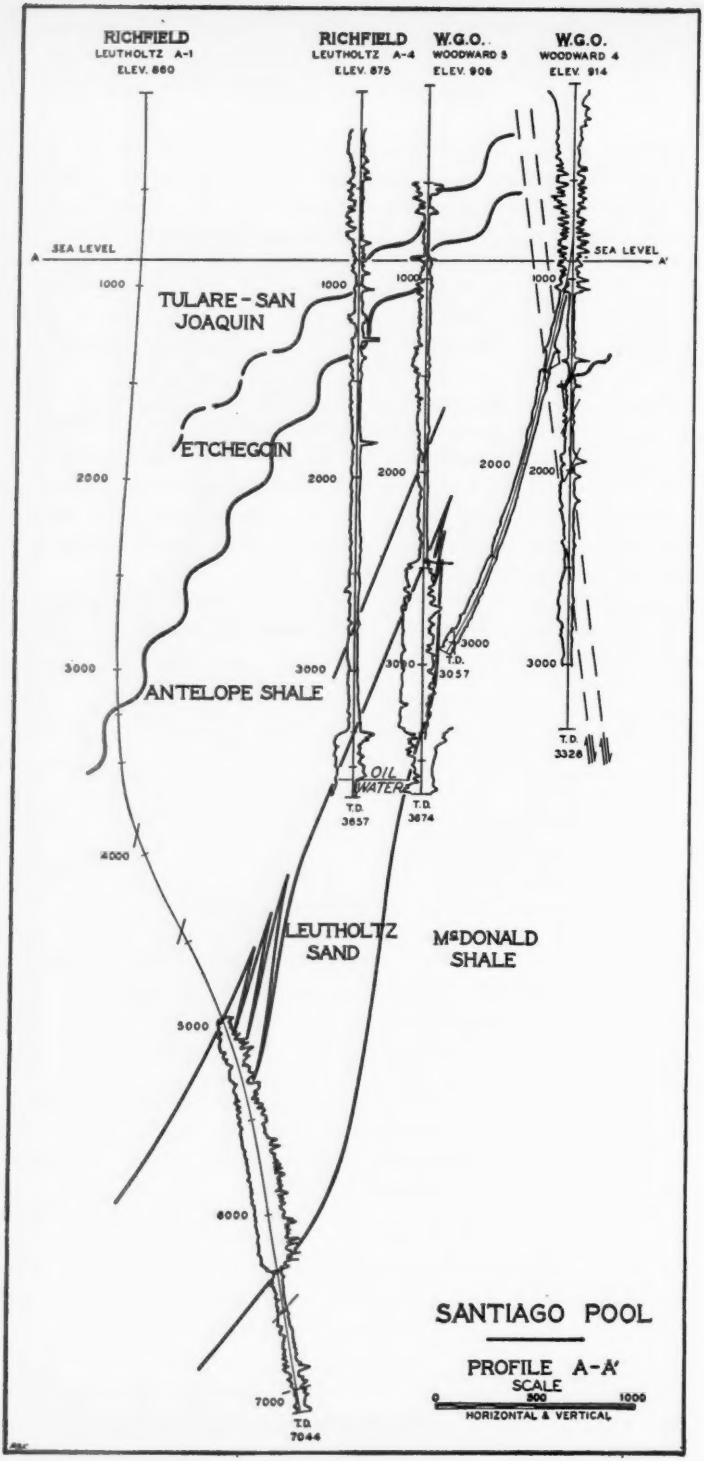

RICHFIELD
LEUTHOLTZ A-1
ELEV. 880
RICHFIELD
LEUTHOLTZ A-4
ELEV. 875
W.G.O.
WOODWARD 3
ELEV. 906
W.G.O.
WOODWARD 4
ELEV. 914
SEA LEVEL
A
A'
TULARE - SAN JOAQUIN
ETCHEGOIN
ANTELOPE SHALE
LEUTHOLTZ SAND
McDONALD SHALE
OIL
WATER
T.D. 3057
T.D. 3326
T.D. 3657
T.D. 3674
T.D. 7044
1000
2000
3000
4000
5000
6000
7000
SANTIAGO POOL
PROFILE A-A'
SCALE
0
500
1000
HORIZONTAL & VERTICAL

FIG. 2

carried across the pinch-out line, without evidence of faulting, in at least three places throughout the length of the pool. Faunal information immediately south of the pinch-out line seems to support this theory. The south productive limit is not a straight line, resembling a pinch-out rather than a fault. Since the eastern productive limit has not been reached, definite proof of pinch-out in that direction will be lacking until more development takes place. The evidence to date, however, seems to indicate a shaling-out of the sand toward the east.

The reader will note from the profile (Fig. 2) that overturned strata were found in the Western Gulf's Woodward No. 4 immediately south of the pinch-out line. This same condition occurs in the General Petroleum's B.M.Q. well No. 1 in Sec. 20, southwest of the pinch-out and was proved in the Leutholtz sand in the Richfield's Leutholtz-A well No. 13 in Sec. 22. Very steep dips are present in the easternmost well in the pool, the Western Gulf's Case No. 1 in Sec. 23. Farther east the whole section may be overturned and the operators will have the unique experience of penetrating the base of the sand before reaching its top.

The northern limit of production in the Santiago pool is the intersection of the oil-water interface and the top of the sand. Three wells have reached the water table and have demonstrated that it is essentially horizontal at 2687 feet sub-sea.

The age of the Leutholtz sand has been determined within rather narrow limits. The brown shale above the sand has been definitely determined to be the equivalent of the Antelope shale of the west side of the San Joaquin Valley and is upper Miocene. The fauna found in shale breaks in the sand in one well and immediately below the sand in several wells is a mixture of Antelope and dwarf McDonald shale faunas. Thus the Leutholtz sand is definitely upper Miocene and may either belong in the basal part of the Antelope or be a sand that is the age equivalent of the basal Antelope shale and uppermost McDonald shale.

Although the maximum stratigraphic thickness of the Leutholtz sand within the limits of the pool is less than 300 feet, the steep dip allows considerable penetration of the oil zone. As an illustration, the Western Gulf's Woodward No. 5 on the accompanying profile penetrated 885 feet of sand zone, about 92 per cent of this thickness being sand. The great sand thickness and the high permeabilities and porosities will allow this pool to have a very high yield per surface acre.

Due to the extreme narrowness of the pool and the steep dips, it is essential to keep the wells relatively straight and to have good directional surveys of as many wells as possible. Several of the earlier wells were not directionally surveyed and this has been a serious handicap in constructing accurate contour maps and locating the south productive limit. As most surveyed wells have drifted updip toward the south, it has been assumed that the unsurveyed wells did likewise. By using this information and by remaining within the maximum drift indicated by single-shot surveys, reasonably accurate locations for the top of the sand have been obtained for wells not directionally surveyed. These points, since they meet with the approval of a majority of the operators, have been used in contouring and reserve studies.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 11 (NOVEMBER, 1947), PP. 2068-2073

# REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

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## REVIEW OF PETROLEUM GEOLOGY IN 1946, BY F. M. VAN TUYL, W. S. LEVINGS, ET AL.

REVIEW BY JOHN L. FERGUSON[1]
Tulsa, Oklahoma

*"Review of Petroleum Geology in 1946," by F. M. Van Tuyl and W. S. Levings, with contributions by faculty members of the Colorado School of Mines and others. *Colorado School of Mines Quarterly*, Vol. 42, No. 3 (July, 1947). 316 pp. including table of contents, abstract, introduction, bibliography, and one illustration. Price, $2.50.

This fifth annual review is small in size but monumental in accomplishment. In 6 months after the close of 1946, the whole field of petroleum geology and the sciences and activities related to it has been surveyed, its literature digested, its accomplishments assessed, and the edited text with a classified bibliography of 3,000 titles has been published in a compact bulletin of 316 pages. The preparation and publication of the bibliography alone would have been an achievement, but the additional research, compilation, and editing of this published information as well as much unpublished material into an integrated text makes this review a real achievement.

The text in this review follows the subdivisions of previous years, using the following section heads: Important Developments of the Year (news-worthy incidents affecting men and societies), 28 pages; Advances in Petroleum Geology and Allied Subjects, 69 pages; Aerial Photographs, 3 pages; World Exploration and Development, 76 pages; Production and Reserves, 9 pages; Trends in Petroleum Geology, 7 pages; Future of the Oil Industry, 4 pages. This textual information is followed by a comprehensive bibliography of about 3,000 titles, classified under the same headings as the text, thus permitting ready reference to the available literature on anything pertinent to petroleum geology in 1946.

The most striking feature of these annual reviews is the amazing increase in volume of information presented in the 5 years of publication. In 1942, the review used 75 pages to take care of the available information, but in 1946, it has taken 316 pages to cover the field adequately. The growth has been continuous during the 5 years but the increase has been brought about by the expansion of certain sections rather than by uniform increase in coverage. The chief enlargements have been in the section on World Exploration and Development and in the Bibliography. Both of these parts were somewhat inadequate in the early reviews and their present size is more in proportion to their importance in such a compilation.

Particular mention should be made of the excellent reports on world exploration and development, submitted directly to this review by well qualified observers most of whom were resident in the prospective and productive oil areas under discussion. The Soviet Union seems to be the only area where insufficient information was available to permit its inclusion in this informative section. Similar direct reports by responsible officers give a brief résumé of the activities of the geological societies and the State and Federal geological surveys during 1946.

The research committee of the Association is indeed fortunate to have found such an able and zealous group as the faculties of geology, geophysics, and petroleum engineering

[1] Amerada Petroleum Corporation. Review received, September, 1947.

at the Colorado School of Mines, to carry on the tremendous and continuous task of bringing out these annual reviews. Dr. Van Tuyl and his associates and contributors are to be congratulated on the successful completion of their fifth and most comprehensive annual review at the time when the spade-work on the sixth was well underway.

The importance of this publication as a reference-book for petroleum geologists, exploration geophysicists, and petroleum engineers is paramount, and its extensive and up-to-date bibliography should make it valuable to other technical men less immediately concerned with the oil business.

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## ELEMENTS OF GEOLOGY FOR WESTERN AUSTRALIAN STUDENTS, BY E. DE C. CLARKE, R. T. PRIDER, AND C. TEICHERT

REVIEW BY BURTON WALLACE COLLINS[1]
Timaru, New Zealand

*Elements of Geology for Western Australian Students*, by E. de C. Clarke, R. T. Prider, and C. Teichert of the department of geology, University of Western Australia. xii+311 pp., frontispiece (geological map), 117 figs. The University of Western Australia Text Books Board, Crawley (1944). Price, 21 s. (Aust.)

While petroleum exploration is almost at a standstill in New Zealand at present after several years of great activity with discouraging results, across the Tasman Sea the search is now being prosecuted with renewed vigor. The book under review was published before the present operations in Australia got under way and makes no explicit reference to the areas now being investigated. It will nevertheless interest petroleum geologists for the background it gives to current activities, as well as for the short section (pp. 158–61) on "Petroleum and Similar Substances in Australia."

Two excellent articles in recent issues of this *Bulletin* by one of the authors[2] cover certain aspects of the geology of Western Australia in much greater detail, but those interested will find in this book answers to many of the questions that must have arisen in their minds about the geology of the state. Although intended primarily for Western Australian university students, the book should easily succeed in fulfilling the authors' hope "that it will also be useful to others desiring information about the geological processes that are most active in Western Australia or about the geological history of this part of the continent." From the point of view of the already trained geologist the book is, indeed, ideal, since most of the elementary parts of the subject are very briefly treated—in the words of the preface again, "students being expected to study them in more detail in the books to which reference is given." Moreover, "very little space is taken up with systematic mineralogy, petrology, or palaeontology, because Western Australian students have a laboratory manual which contains sufficient elementary information on these subjects."

The book is well printed on fair quality paper and generously illustrated with text figures. Probably for reasons of cost there are no plates, which is a noticeable lack in a work of this type. However, the landscape of Western Australia gives little scope for the

[1] New Zealand Geological Survey, Box 250, Timaru, South Canterbury, New Zealand. Manuscript received, September 16, 1947.

[2] C. Teichert, "Stratigraphy of Western Australia," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 31, No. 1 (January, 1947), pp. 1–70.
———, "Upper Paleozoic of Western Australia: Correlation and Paleogeography," *ibid.*, Vol. 25, No. 3 (March, 1941), pp. 371–415.

photographer, though a few will be found in the first paper cited in the footnote.[3] The size ($7\frac{1}{2}\times9\frac{1}{2}$ inches) is somewhat inconvenient for some purposes. There is a full 11-page double-column index and a list of illustrations.

Numerous references to original articles are given at the end of each chapter. References to other parts of the book are, unfortunately, not to pages, but to chapters, sections, and sub-sections. Since these subdivisions do not appear either in the list of contents or in the page headings, a good deal of page-turning and text-searching has to be done in order to find the passages required.

After a short introduction including a summary of the history of geological research in the state, the book is divided into two parts. In the first, dealing with physical geology, more emphasis than usual is placed on processes such as arid erosion and metamorphism that are, or have been, very important in Western Australia. There is a particularly interesting chapter on underground water, describing among other topics the artesian basins of Australia. In the second part, on historical geology, a notable feature is the set of paleogeographic maps of Australia, which, again to quote the preface, "gives an approach to a 'moving picture' of the evolution of Australia to its present geographic form, there being more than one map for some of the geological periods—a detail that has perhaps not been attempted in other summaries of Australian geological history." In the text, although Western Australia is treated in more detail, there are adequate summaries of the stratigraphy of the other states of the Commonwealth. An interesting section of the introductory chapter of this part of the book is one of seven pages on "Development of Ideas Regarding the History of the Earth," which is calculated to whet the appetites of readers and encourage them to seek elsewhere more information on the history of their science.

It may be mentioned that the senior author, E. de C. Clarke, who has for many years been professor of geology in the University of Western Australia, is a former New Zealander, and was at one time on the staff of the New Zealand Geological Survey. Those members of the Association who have been in any way concerned with petroleum exploration in New Zealand will no doubt remember and appreciate his still valuable account of the New Plymouth area, New Zealand's only oil field.[4]

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## ROCKS AND ROCK MINERALS, BY LOUIS V. PIRSSON AND ADOLPH KNOPF

**Rocks and Rock Minerals*, by Louis V. Pirsson, 3d edition (1947) revised by Adolph Knopf. 349 pp., 72 figs., 36 pls. 5.5×8.375 inches. Cloth. John Wiley and Sons, Inc., New York. Price, $4.00.

The guiding principles underlying Professor Knopf's preparation of the third edition were simplicity, clarity, and brevity. Considerable detail has been eliminated to permit clearer definition and fuller explanation of the more important fundamentals. In classifying rocks, petrographic definitions are stressed, while purely descriptive terms are urged for field use. Explanation is given of the principal petrographic and petrologic terms, so that users may gain a clearer understanding of areal geologic accounts and of reports on mining districts.

The chapters on the highly important and difficult sedimentary rocks have been entirely rewritten and reorganized to include the latest information. Treatment of metamorphic and igneous rocks is likewise up to date. Significant chemical analyses of rocks

[3] C. Teichert, "Stratigraphy of Western Australia," *op. cit.*, photographs bet. pp. 8 and 9.

[4] E. de C. Clarke, "The Geology of the New Plymouth Subdivision, Taranaki Division," *New Zealand Geol. Survey Bull. 14* (1912). 58 pp.

with their mineral composition and specific gravity are given throughout the text, wherever such inclusion would be helpful.

*Rocks and Rock Minerals*, in its earlier editions, has been acclaimed as " . . . one of the best works on geology which has been issued in America," and, "unexcelled . . . an extraordinarily good and well presented source of information and facts of petrology on the megascopic level."

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## COMPILACION DE LOS ESTUDIOS GEOLOGICOS OFICIALES EN COLOMBIA

REVIEW BY GEORGE T. BECKER[1]
Bogotá, Colombia

**Compilación de los Estudios Geológicos Oficiales en Colombia*, Tomo VII, *Ministerio de Minas y Petróleos, Servicio Geológico Nacional* (Bogotá, 1947). 346 pp., 86 pls. 23 articles by 10 authors. In Spanish and English. Approx. 6.75×9.75 inches. Paper cover.

The National Geological Survey of Colombia, under the direction of Alejandro Del Río M., has recently published Volume VII of its official geological studies.

Volume VII, like its predecessors, is a compilation of studies and surveys which were both pure science and officially authorized research. However, inasmuch as the plan of study and report is consistent, many interesting geological data are embodied in the reports which are not purely scientific but are studies of a geological nature authorized by the Ministry of Mines and Petroleum.

The total compilation in Volume VII includes eight studies of water supply, three of which are hydro-electric; nine studies of mineral and ore occurrences; one study of quarry operations in Bogotá; three studies of landslides; and the first two papers (in English) of a series devoted to the vertebrate collections made in Colombia in 1944 and 1945 by R. A. Stirton of the Museum of Paleontology, University of California, and José Royo y Gómez of the Colombia National Geological Survey. The final evaluation of these latter studies promises to yield a large amount of valuable stratigraphic information.

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## RECENT PUBLICATIONS

### ALASKA

*"Exploration in Alaska," by K. Marshall Fagin. *Petrol. Engineer*, Vol. 18, No. 13 (Dallas, September, 1947), pp. 150–64; 3 figs., 11 photographs.

### AUSTRALIA

*"Foraminifera in the Permian Rocks of Australia," by Irene Crespin. *Australia Bur. Min. Resources, Geology, and Geophysics Bull. 15*, Paleon. Ser. 5 (1947). 26 pp., 2 pls., 1 fig., 4 tables. Dept. Supply and Shipping, Canberra, Australia.

### CUBA

*"Eocene Discocyclinidae and Other Foraminifera from Cuba," by W. Storrs Cole and Pedro J. Bermudez. *Bulletins Amer. Paleon.*, Vol. 31, No. 125 (Paleontological Research Inst., Ithaca, New York, September 18, 1947). 33 pp., 7 pls.

[1] Mene Grande Oil Company. Review received, September 26, 1947.

ENGLAND

*"The Geology of the Evenlode Gorge, Oxfordshire," by W. J. Arkell. *Proc. Geologists' Assoc.*, Vol. 58, Pt. 2 (Colchester, September 29, 1947), pp. 87–114; 3 pls. (folded), 2 tables, 4 figs. Describes the Oölite series of the Jurassic. Printed by Benham and Company Ltd., High Street, Colchester. Price for complete number of Part 2: 5 sh.

GENERAL

*"New Techniques in Aerial Surveying. Pt. 3, Photogrammetric Processes," by Sherman A. Wengerd. *World Oil*, Vol. 125, No. 7 (Houston, September 29, 1947), pp. 49–54, Figs. 3–4.

*"Penn Grade Progress on Use of Bacteria for Releasing Oil from Sands," by Jay V. Beck. *Producers Monthly*, Vol. 11, No. 11 (Bradford, Pennsylvania, September, 1947), pp. 13–18; 2 figs., 1 table.

**Tulsa Geological Society Digest*, Vol. 15 (1947). 116 pp. Abstracts of papers presented before the Society from October, 1946, to June, 1947. Robert F. Walters, editor. 6×9 inches. Paper cover. Obtainable from Tulsa Geological Society, V. L. Frost, secretary-treasurer, c/o Ohio Oil Company, Thompson Building, Tulsa, Oklahoma. Price, $0.50.

*"Bibliography of Seismology No. 20, Items 6143–6356, July to December, 1946," by Ernest A. Hodgson. *Pub. Dominion Observatory*, Vol. XIII (Ottawa, 1947), pp. 331–71. Canada Dept. Mines and Resources. Price, $0.25.

*"Well Logging Methods Conference," by School of Engineering, Department of Petroleum Engineering, held at the Agricultural and Mechanical College of Texas, March 11–15, 1946. *A. & M. College Texas Bull. 93*, Vol. 1, No. 8, 5th Ser. (College Station, August 15, 1945). 171 pp., 13 papers. Single copy, free; multiple copies, 25¢ each, by addressing Engineering Experiment Station, A. & M. College of Texas, College Station, Texas.

*"Terrestrial Heat and Earth Movements," by A. J. Bull. *Proc. Geologists' Assoc.*, Vol. 58, Pt. 2 (Colchester, England, September 29, 1947), pp. 115–24; 3 figs.

HAWAII

*"Origin and Development of Craters," by T. A. Jaggar. *Geol. Soc. America Mem. 21* (New York, August 15, 1947). 508 pp., 87 pls., 14 figs.

KANSAS

*"The Late Pleistocene Loesses of Central Kansas," by John C. Frye and O. S. Fent. *Kansas Geol. Survey Bull. 70*, Pt. 3 (Lawrence, September 15, 1947), pp. 29–52, Figs. 1–3, Pls. 1–2.

*"Subsurface Geologic Cross Section from Ford County, Kansas, to Dallam County, Texas," by Fanny Carter Edson. *Kansas Geol. Survey Oil and Gas Inves. Prelim. Cross Sec. 3* (Lawrence, 1947). Sheet, 39×38 inches.

MISSISSIPPI

*"New Upper Cretaceous Fossils from Mississippi and Texas. Part 1. Fossils from Two Deep Wells in Mississippi," by Lloyd William Stephenson. *U. S. Geol. Survey Prof. Paper 210-E* (1947), pp. 161–85, Pls. 31–33. For sale by Supt. Documents, Govt. Printing Office, Washington 25, D.C.

NEW MEXICO

*"New Mexico Oil and Gas Production Data for 1946 (Exclusive of Lea County)," compiled by N. Raymond Lamb and W. B. Macy. *New Mexico Bur. Mines and Min. Res. Cir. 16* (Socorro, 1947). 171 pp., multigraphed. 8.375×11.625 inches. Paper covers.

NORTH DAKOTA

*"The Geology and Ground Water Resources of the Flora Quadrangle," by John R. Branch. *North Dakota Geol. Survey Bull. 22* (Grand Forks, 1947). 35 pp., 2 pls., 5 figs., 3 tables.

OKLAHOMA

*"Anadarko Basin: Geology and Oil Possibilities. Pt. 2, Stratigraphy and Reservoir Rocks," by Robert R. Wheeler, *World Oil*, Vol. 127, No. 5 (Houston, September 29, 1947), pp. 33–46, Figs. 2–8.

TEXAS

*"New Upper Cretaceous Fossils from Mississippi and Texas. Part 2. A New Venericardia from Uvalde County, Texas," by Lloyd William Stephenson. *U. S. Geol. Survey Prof. Paper 210-E* (1947), pp. 185–98, Pls. 31–33. For sale by Supt. Documents, Govt. Printing Office, Washington 25, D.C.

TURKEY

*"Note sur la stratigraphie générale de la Turquie" (Stratigraphy of Turkey), by V. Stchépinsky. *Bull. Soc. Géol. France*, 5th Ser., Vol. 16, Nos. 4, 5, 6 (1946), pp. 347–62. French. 28 rue Serpente, Paris VI (May, 1947).

WEST TEXAS-NEW MEXICO

*"West Texas-New Mexico Permian Basin Oil Fields, Geological Data, Development History," compiled by H. H. King and Gilbert M. Wilson. *World Oil*, Vol. 127, No. 6 (Houston, October, 1947), pp. 271–334, with insert folded map in colors.

WYOMING

*"Stratigraphic Sections of Mesozoic Rocks in Central Wyoming," by J. D. Love, H. A. Tourtelot, C. O. Johnson, R. M. Thompson, H. H. R. Sharkey, and A. D. Zapp. *Wyoming Geol. Survey Bull. 38* (Laramie, June, 1947). 59 pp., 8 figs. Price, $2.00.

*"Shallow Sand Traps in Wyoming," by Henry Carter Rea. *Oil Reporter*, Vol. 4, No.6 (Denver, October 7, 1947), pp. 8–9, 28; 2 figs.

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DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Sedimentary Petrology* (Tulsa, Oklahoma), Vol. 17, No. 2 (August, 1947)

"Pisoliths and Oöliths from Some Australian Caves and Mines," by George Baker and A. C. Frostick

"Trinity Sediments of North and Central Texas," by Raymond Sidwell

"Current Crescents in the Triassic Moenkopi Formation," by Frank E. Peabody

"Mathematical Derivation of the Unique Frequency Curve," by G. R. Brotherhood and J. C. Griffiths

"Cleaning Mineral Grains for Petrographic Study," by Charles M. Gilbert

"A Mercury Valve for Separating Heavy Minerals by Thoulet or Sonstadt Solution ($K_2HgI_4$)," by C. P. Sud

"Contributions to the Journal of Sedimentary Petrology," by K. O. Emery

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### REPRESENTATIVES ON COUNCIL OF AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

W. TAYLOR THOM, JR. ROBERT J. RIGGS

### COMMISSIONERS ON AMERICAN COMMISSION ON STRATIGRAPHIC NOMENCLATURE

M. G. CHENEY (1947), *chairman* JOHN G. BARTRAM (1948) WAYNE V. JONES (1949)

## *STANDING COMMITTEES*

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### BUSINESS COMMITTEE

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FRANK R. CLARK (1948)
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CARLE H. DANE (1948)
CARROLL E. DOBBIN (1949)
STANLEY G. ELDER (1948)
FENTON H. FINN (1949)
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J. M. PATTERSON (1949)
E. E. Rehn (1949)
J. T. RICHARDS (1949)
J. J. RUSSELL, JR. (1948)
LOWELL W. SAUNDERS (1949)
HARRY C. SPOOR, JR. (1949)
HENRYK B. STENZEL (1948)
D. E. TAYLOR (1948)
HENRY N. TOLER (1949)
C. W. TOMLINSON (1948)
JAMES A. WATERS (1948)
SAM H. WOODS (1949)

## COMMITTEE FOR PUBLICATION

LYNN K. LEE (1948), *chairman*, Pure Oil Company, Fort Worth, Texas

| 1948 | 1949 | 1950 |
|---|---|---|
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| W. S. HOFFMEISTER | GEORGE C. GROW | HOLLIS D. HEDBERG |
| J. M. KIRBY | BENJAMIN F. HAKE | G. L. MEHOLIN |
| E. RUSSELL LLOYD | MASON L. HILL | E. FLOYD MILLER |
| HOMER A. NOBLE | GEORGE S. HUME | VINCENT C. PERINI, JR. |
| THOMAS F. STIPP | JAMES A. MOORE | PAUL H. PRICE |
| C. W. WILSON, JR. | ROBERT B. NEWCOMBE | E. E. REHN |
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| | | K. K. SPOONER |

## RESEARCH COMMITTEE

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| 1948 | 1949 | 1950 |
|---|---|---|
| RONALD K. DEFORD | L. C. CASE | ROLAND F. BEERS |
| MARCUS A. HANNA | PARKE A. DICKEY | G. C. GESTER |
| MARSHALL KAY | K. C. HEALD | JOHN T. LONSDALE |
| PHILIP B. KING | WILLIAM C. IMBT | C. V. MILLIKAN |
| A. I. LEVORSEN | W. C. KRUMBEIN | L. L. NETTLETON |
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| L. G. WEEKS | W. A. WALDSCHMIDT | W. H. TWENHOFEL |
| | OSCAR G. WILHELM | CLAUDE E. ZOBELL |

## GEOLOGIC NAMES AND CORRELATIONS COMMITTEE

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| 1948 | 1949 | | 1950 |
|---|---|---|---|
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| ROBERT H. DOTT | ROLLIN ECKIS | GAYLE SCOTT | ROY T. HAZZARD |
| E. FLOYD MILLER | ROSS L. HEATON | G. D. THOMAS | W. J. HILSEWECK |
| HUGH D. MISER | J. H. C. MARTENS | H. D. THOMAS | P. H. JENNINGS |
| RAYMOND C. MOORE | TOM MCGLOTHLIN | ROBERT O. VERNON | WAYNE V. JONES |
| | GROVER E. MURRAY | L. E. WORKMAN | W. ARMSTRONG PRICE |
| | | | H. A. TOURTELOT |

### SUB-COMMITTEE ON CENOZOIC

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ROLLIN ECKIS (Pacific Coast)
TOM MCGLOTHLIN (Eastern Gulf Coast)
PHILIP H. JENNINGS (Western Gulf Coast)
HARRY A. TOURTELOT (Rocky Mts. and Great Plains)

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G. D. THOMAS (1949), *chairman*, Shell Oil Company, Inc., Shreveport, Louisiana

R. T. HAZZARD (Gulf Coast)
ROSS L. HEATON (Rocky Mts. and Great Plains)
HORACE G. RICHARDS (Atlantic Coast)

### SUB-COMMITTEE ON PALEOZOIC

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STUART K. CLARK (Mid-Continent)
L. E. WORKMAN (Eastern Interior)
W. J. HILSEWECK (Southwestern U. S. A.)
J. H. C. MARTENS (Appalachian Region)

### ADVISORY AND SPECIAL PROJECTS SUB-COMMITTEE

JOHN G. BARTRAM (1948), *chairman*, Stanolind Oil and Gas Company, Tulsa, Oklahoma

| | | |
|---|---|---|
| ARTHUR E. BRAINERD | E. FLOYD MILLER | RAYMOND C. MOORE |
| WAYNE V. JONES | HUGH D. MISER | W. ARMSTRONG PRICE |
| | | GAYLE SCOTT |

## COMMITTEE ON APPLICATIONS OF GEOLOGY

KENNETH K. LANDES (1948), *chairman*, University of Michigan, Ann Arbor, Michigan

| 1948 | 1949 | 1950 |
|---|---|---|
| ROBERT I. DICKEY | E. M. BAYSINGER | DON L. CARROLL |
| CHARLES R. FETTKE | CHARLES J. DEEGAN | STANLEY G. ELDER |
| OLAF P. JENKINS | L. B. HERRING | LEO R. FORTIER |
| NICHOLAS A. ROSE | R. A. STEHR | THOMAS A. HENDRICKS |
| | | W. T. NIGHTINGALE |
| | | W. T. SCHNEIDER |

## MEDAL AWARD COMMITTEE

CARROLL E. DOBBIN, *chairman*, U. S. Geological Survey, Denver, Colorado
JAMES A. WATERS, *ex officio*, president of S.E.P.M.
CECIL H. GREEN, *ex officio*, president of S.E.G.

| 1948 | 1949 | 1950 |
|---|---|---|
| A. RODGER DENISON | RUSSELL S. MCFARLAND | FRANK R. CLARK |
| VIRGIL B. COLE | RAYMOND F. BAKER | ALFRED H. BELL |
| J. EDMUND EATON | C. R. MCCOLLOM | A. E. BRAINERD |

## COMMITTEE ON STATISTICS OF EXPLORATORY DRILLING

F. H. LAHEE (1950), *chairman*, Sun Oil Company, Box 2880, Dallas, Texas
PAUL WEAVER (1948), *vice-chairman*, Gulf Oil Corporation, Box 2100, Houston, Texas

| 1948 | 1949 | 1950 |
|---|---|---|
| KENNETH COTTINGHAM | STANLEY G. ELDER | A. H. BELL |
| RALPH E. ESAREY | COLEMAN D. HUNTER | S. A. BERTHIAUME |
| FENTON H. FINN | ROBERT C. LAFFERTY, JR. | G. P. CRAWFORD |
| JOHN W. INESTER | D. J. MUNROE | R. J. CULLEN |
| GRAHAM B. MOODY | T. F. PETTY | W. S. MCCABE |
| CHARLES H. ROW | GLENN C. SLEIGHT | E. L. REED, JR. |
| | PAUL H. UMBACH | R. M. WILSON |
| | C. W. WILSON | |

## DISTINGUISHED LECTURE COMMITTEE

FRED H. MOORE (1949), *chairman*, Magnolia Petroleum Company, Roswell, New Mexico

| 1948 | 1949 | 1950 |
|---|---|---|
| EVERETT F. STRATTON | HUGH R. BRANKSTONE | W. J. HILSEWECK |
| CARROLL M. WAGNER | JOHN L. FERGUSON | H. T. MORLEY |

## *SPECIAL COMMITTEES*

## COMMITTEE ON BOY SCOUTS LITERATURE

FRANK GOUIN, *chairman*, Box 208, Duncan, Oklahoma

| | | |
|---|---|---|
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| MAX W. BALL | CAREY CRONEIS | W. T. THOM, JR. |
| HAL P. BYBEE | E. C. DAPPLES | RUSSELL M. TRIPP |
| DON L. CARROLL | G. W. PIRTLE | MARTIN VAN COUVERING |

## EDUCATION COMMITTEE

ROY R. MORSE, *chairman*, Shell Oil Company, Box 2099, Houston, Texas

| | | |
|---|---|---|
| STUART K. CLARK | RONALD K. DEFORD | THERON WASSON |
| MORGAN J. DAVIS | HENRY V. HOWE | |

## MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

**The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa 1, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)**

FOR ACTIVE MEMBERSHIP

Robert Garwood Couch, Caracas, Venezuela, S. A.
Ely Mencher, P. P. Conrad, Albert J. Z. Caan
Roy Hayes Guess, Corpus Christi, Tex.
W. A. Maley, G. B. Gierhart, C. E. Buck
John Rodefer Harris, Ardmore, Okla.
C. E. Hannum, William R. Johnson, J. J. Galloway
George Edward Hatton, Amarillo, Tex.
T. C. Craig, E. A. Paschal, E. W. Fosshage
Arthur Lionel Hill, San Carlos, Calif.
Elmo W. Adams, Downs McCloskey, Graham B. Moody
James Harold McLay, Caracas, Venezuela, S. A.
Thomas C. Wilson, Robert H. Robie, D. W. Gravell
George Oliver Morgan, Jr., Houston, Tex.
A. P. Wendler, D. P. Carlton, J. Ben Carsey
Frank Watson Parent, Houston, Tex.
John D. Todd, W. Harlan Taylor, Ray C. Lewis
Willem Anthony Visser, The Hague, Holland
J. J. Dozy, C. E. Thiebaud, R. Martin
Maurice H. Wallace, Casablanca, Morocco
Edward J. Foley, Walter K. Link, M. A. Dresser

FOR ASSOCIATE MEMBERSHIP

Felipe Eduardo Baldo, Caracas, Venezuela, S. A.
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Carle Sheldon Boyer, Mattoon, Ill.
L. L. Whiting, Jack Hirsch, George T. Crouse
Marvin Reece Burditt, Tulsa, Okla.
Jess Vernon, Jerry E. Upp, J. F. Hosterman
Robert James Butler, Vernal, Utah
Philip A. Williams, H. B. Fields, Edward L. Tullis
Charles Alfred Caswell, Duncan, Okla.
Carl L. Maxey, D. M. Putnam, Charles R. Rider
James D. Elder, Wichita, Kan.
Jackson M. Barton, Frank E. Lewis, Don W. Payne
George H. Hall, Spring Hill, W. Va.
J. E. Billingsley, R. L. Alkire, A. Y. Barney
James Vincent Hardwick, Midland, Tex.
Dana M. Secor, Niles B. Winter, W. J. Hilseweck
Leroy Delville Holcomb, Tacoma, Wash.
W. Layton Stanton, W. W. Heathman, Harold E. Culver

(*Continued on page 2088*)

## NOMINEES FOR OFFICERS, 1948–1949

### For President

PAUL WEAVER

Chief geophysicist, Gulf Oil Corp., Houston
Born, May 18, 1888, Carrollton, Ky.

*Academic Training*

| | |
|---|---|
| 1904–08 | Columbia University<br>Mathematics, Geology A.B., 1908 |

*Experience*

| | |
|---|---|
| 1908–09 | U. S. Coast and Geodetic Survey |
| 1909–10 | U. S. Geological Survey |
| 1910–11 | Bermudez Company, Trinidad, Venezuela |
| 1912–14 | S. Pearson and Son, Mexico |
| 1914–15 | Whitehall Petroleum Corporation |
| 1916–26 | Cia. El Aguila, Mexico |
| 1926– | Gulf Oil Corporation |

*Publications.*—Field of geology, geophysics, and petroleum engineering

*Professional Affiliation (National)*

Amer. Assoc. Advancement of Science
Amer. Geophysical Union
Amer. Inst. Min. Met. Engineers
Amer. Soc. for Metals
Geological Society of America
Seismological Society
Society of Economic Geologists
Society of Exploration Geophysicists

*A.A.P.G. Activity*

| | |
|---|---|
| 1933–34; 42 | Business Committee |
| 1937–38 | Committee for Publication |
| 1941–43 | Research Committee |
| 1942 | Vice-President |
| 1942–46 | Applications of Geology (Chm., 43–44) |
| 1946–48 | Statistics of Exploratory Drilling (Vice-Chm.) |

### For Vice-President

ROY MERRILL BARNES

Regional geologist, Continental Oil Co., Los Angeles, Calif.

Born, Nov. 10, 1891, Los Angeles, Calif.

*Academic Training*

| | |
|---|---|
| 1911–16 | Univ. of California (Berkeley)<br>Civil Engineering B.S., 1917 |

*Experience*

| | |
|---|---|
| 1919–24 | California State Mining Bur., Dept. Petroleum and Natural Gas |
| 1924–28 | Marland Oil Co. of California |
| 1928– | Continental Oil Co. |

*Military Service*

| | |
|---|---|
| 1917–19 | Army (Engineers) |

*Publications*—Engineering and geology

*Professional Affiliation (National)*

Amer. Inst. Min. Met. Engineers

*A.A.P.G. Activity*

| | |
|---|---|
| 1935–36; 47 | Business Com. (Vice-Chm. 47) |
| 1939 | Com. for Studying Methods of Electing Officers |
| 1941–45 | Com. on Applications of Geology |

FOR SECRETARY-TREASURER

J. V. HOWELL

Consultant, Tulsa, Oklahoma

Born, March 11, 1891, Oskaloosa, Iowa

*Academic Training*

| | |
|---|---|
| 1908–12 | Penn College (Iowa)<br>Chemistry B.S., 1912 |
| 1913–16 | University of Iowa<br>Geology M.S., 1915 |
| 1921–22 | Geology Ph.D., 1922 |

*Experience*

| | |
|---|---|
| 1916–18 | The Texas Company |
| 1918–21 | Gypsy Oil Company |
| 1921–22 | Univ. Iowa, instructor, geology |
| 1922–29 | Marland Oil Company |
| 1929– | Consulting geologist, Tulsa |

*Military Service.*—Field Artillery, 1918

*Publications.*—Field of structural, economic, and petroleum geology

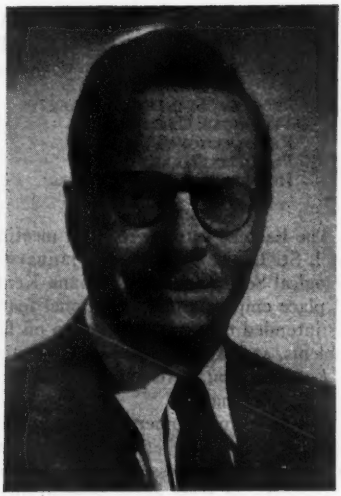
*Professional Affiliation (National)*

Geological Society of America

*A.A.P.G. Activity*

| | |
|---|---|
| 1927; 39; 46–47 | Bus. Com. (Vice-Chm., 46) |
| 1930 | Com. on Method Election of Officers |
| 1936–38 | Trustee, Revolving Publ. Fund |
| 1940 | Com., New Way for Electing Officers |
| 1942–44 | Chm., Com. for Publication |
| 1945 | Vice-Chm., Com. for Publication |
| 1947–48 | Editor, Struc. Typical Amer. Oil Fields, Vol. III |
| 1948 | Secretary-Treasurer |

FOR EDITOR



C. L. MOODY

Division geologist, The Ohio Oil Co., Shreveport, La.

Born, Oct. 26, 1888, Compton, Calif.

*Academic Training*

| | |
|---|---|
| 1909–10 | Univ. of Southern California |
| 1912–16 | Univ. of California<br>Geology A. B., 1916 |
| 1917 | Univ. of California<br>Geology graduate student |

*Experience*

| | |
|---|---|
| 1917–18 | Consulting geologist, Casper, Wyo. |
| 1918– | The Ohio Oil Co. |

*Publications.*—Field of stratigraphy and structure of Rocky Mountains and Gulf Coast areas

*Professional Affiliation (National)*

Amer. Assoc. Advancement of Science
Geological Society of America

*A.A.P.G. Activity*

| | |
|---|---|
| 1932–40 | Geol. Names and Correlations Com. |
| 1933–38 | Associate Editor |
| 1937 | Vice-President |
| 1937; 39–41; 46 | Business Committee |
| 1943–45 | Trustee, Research Fund (Chm., 45) |
| 1943–44 | National Service Com. |
| 1945 | Com., Statistics Explor. Drilling |
| 1945 | Com., Method of Election of Officers |
| 1946–47 | Business Com. (Vice-Chm., 46; Chm., 47) |
| 1948 | Editor |

## EASTERN INTERIOR REGIONAL MEETING
## ST. LOUIS, JANUARY 14–15, 1948

### GENERAL COMMITTEE

E. E. REHN, *chairman*
Sohio Petroleum Company, Box 537, Mount Vernon, Illinois

PROGRAM: STANLEY G. ELDER
TECHNICAL: CARL BAYS
REGISTRATION: T. E. WALL
PUBLICITY: GENE GADDESS
HOTELS: THEODORE G. GLASS
ENTERTAINMENT: C. E. BREHM
FINANCE: CHARLES A. DOH
EXHIBITS: GIL RAASCH
RECEPTION: HARRY H. NOWLAN

The Eastern Interior regional meeting of the Association will be held at the Jefferson Hotel, St. Louis, Missouri, on January 14 and 15, 1948. It is sponsored by the Illinois Geological Society and the Indiana-Kentucky Geological Society. The technical program will place emphasis on the regional features between the Ozarks and the Appalachians. It is intended to include papers on oil fields, interpretation of electrical logs, geophysical problems, and geological aspects of water flooding. No field trips are being planned.

*Entertainment.*—An informal smoker will be held Tuesday night, January 13. There is no admission charge.

A semi-formal dinner-dance is arranged for Thursday night, January 15, with music furnished by an excellent orchestra. Admission charge will approximate $5.00 per plate and reservations are essential for planning by the entertainment committee.

Indicate on your hotel reservation if you expect to attend either or both of these events.

*Hotel reservations.*—Address all requests for reservations to

Housing Bureau, A.A.P.G.
910 Syndicate Trust Building
Saint Louis 1, Missouri.

Reservations should be made prior to December 31, 1947, and should give all information requested on sample form printed herewith. Be sure to indicate your attendance for the smoker and dinner-dance.

Convention headquarters will be the Jefferson Hotel. All hotels are in the downtown district. The Jefferson has reserved 300 rooms; the Statler, 200; the Lenox, 50; the Mark Twain, 50; the Mayfair, 50; the DeSoto, 50. Prices are shown on included break-down.

Each member is being mailed a copy of the announcement and a hotel reservation form, a sample of which is here printed for information.

### APPLICATION FOR HOUSING ACCOMMODATIONS ST. LOUIS, MO.

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS — JANUARY 14–15, 1948

For your convenience in making hotel reservations for the coming meeting of the American Association of Petroleum Geologists January 14–15, 1948 in St. Louis, hotels and their rates are listed below. Use the form at the bottom of this page, indicating your first, second and third choice. Because of the limited number of single rooms available, you will stand a much better chance of securing accommodations if your request calls for rooms to be occupied by two or more persons. All reservations must be cleared through the housing bureau. ALL REQUESTS FOR RESERVATIONS MUST GIVE DEFINITE DATE AND HOUR OF ARRIVAL AS WELL AS DEFINITE DATE AND APPROXIMATE HOUR OF DEPARTURE, ALSO NAMES AND ADDRESSES OF ALL PERSONS WHO WILL OCCUPY RESERVATIONS REQUESTED MUST BE INCLUDED.

| Hotel | For one person | For two persons Double Bed | For two persons Twin Beds | 2-Room Suites Parlor & Bedroom |
|---|---|---|---|---|
| DE SOTO | 2.75–7.00 | 4.00–7.00 | 6.00–12.00 | 10.50–12.00 |
| JEFFERSON | 3.50–6.00 | 5.00–7.00 | 7.00– 8.00 | 14.00–22.00 |
| LENOX | 3.25–6.00 | 5.00–6.50 | 6.00– 8.00 | 11.00 |
| MARK TWAIN | 3.00–3.50 | 4.50–5.00 | 5.00– 5.50 | |
| MAYFAIR | 3.25–7.00 | 4.50–8.00 | 6.00– 8.00 | 11.00 & Up |
| STATLER | 3.50–6.00 | 5.25–8.00 | 7.25–10.00 | 16.00–19.00 |

In the event that the hotel room rate structure is changed prior to the above convention these rates will be changed accordingly.

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ALL RESERVATIONS MUST BE RECEIVED PRIOR TO December 31, 1947

Housing Bureau, American Association of Petroleum Geologists
910 Syndicate Trust Building,
St. Louis 1, Mo.

Please reserve the following accommodations for the American Association of Petroleum Geologists meeting in St. Louis on January 14–15, 1948

Single Room..... Double Bedded Room..... Twin Bedded Room.....
2 Room Suite..... Other Type of Room.....
Rate: From $.....to $..... First Choice Hotel.....
Second Choice Hotel.....
Third Choice Hotel.....
Arriving at Hotel (date).....hour.....A. M.....P. M. Leaving (date).....
hour.....A. M.....P. M.

THE NAME OF EACH HOTEL GUEST MUST BE LISTED. Therefore, please include the names of *both* persons for *each* double room or twin bedded room requested. Names and addresses of all persons for whom you are requesting reservations and who will occupy the rooms asked for:

.....
.....
.....
.....

(Individual Requesting Reservations)
Name.....
Address.....
City and State.....

If the hotels of your choice are unable to accept your reservation the Housing Bureau will make as good a reservation as possible elsewhere providing that all hotel rooms available have not already been taken.

will
I will not attend smoker

will
I will not attend dinner dance

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 11 (NOVEMBER, 1947), PP. 2082-2084, 1 FIG.

# MEMORIAL

ROBERT ERNEST GARRETT
(1888–1947)

Robert E. Garrett was born February 13, 1888, in Marshalltown, Iowa, the son of Ackley E. and Mary E. Garrett. Death occurred on March 4, 1947, of a heart attack while on a field trip near Bristow, Oklahoma. Although his health had been impaired for several years, and he had been advised that his heart was weakened, Bob could not for long remain idle, and his restless energy impelled him to continue the work he liked best.

His early years were spent in Marshalltown, where he completed his elementary school work. At the close of his first year in high school, when Bob was 17, his parents moved to a farm southwest of Oklahoma City in the new state of Oklahoma. In the fall of that year he enrolled in the preparatory department of the University of Oklahoma at

Norman, completing his high school work in 1908 and continuing in the University. He was graduated in 1912 with a degree of A.B. and a major in geology.

Although he earned much of his living expense, Bob found time to make grades far above average, and to participate in the Glee Club, a debating society, swimming, wrestling, and intramural athletics. During the last three years he served as assistant registrar of the University.

He was a charter member of the Oklahoma University Chapter of Sigma Nu fraternity, and during his Junior year was elected to P. E. E. T., the men's honor society, as one of the ten outstanding men in both scholarship and school activities.

Immediately after graduation in 1912 Bob was employed by the Oklahoma Geological Survey, and began field work in Kay County as assistant to D. W. Ohern. The results of this work were published as the Survey's *Bulletin 16*, "The Ponca City Oil and Gas Field," by D. W. Ohern and Robt. E. Garrett, in December, 1912. This work not only included the area of the Ponca City field, which had been discovered in 1911, but mapped in detail the Mervine anticline, on which no production was found until the following year. This apparently is the first instance of an Oklahoma oil field being discovered on the strength of a published map.

In the fall of 1912 Bob entered Northwestern University as a Fellow, and completed a year of graduate work, serving meantime as a student assistant in mineralogy.

In 1913 the Gypsy Oil Company (now Gulf Oil Corporation) organized the first company geological department in Tulsa, under the direction of M. J. Munn, who had previously been head of the Oil and Gas Section of the United States Geological Survey. Among the first employees was Robert Garrett, who was engaged in field work, first directly under Munn, and later as head of all field studies in this rapidly growing department. This work continued until 1917, and, while devoted largely to Oklahoma, embraced field studies in Kansas, Texas, Colorado, and New Mexico. Bob was an exceptional field geologist, and his work and that of his associates of those years led directly to the discovery of a number of oil pools, of which Fox and Milroy (2–4) may be noted. Anyone who has worked in those areas can appreciate the difficulties involved in cross-bedded sandstones, thick blackjacks and, at that time, few roads.

In 1917 Bob resigned to enter a partnership with J. Russell Crabtree, A. P. Wright, and Jerry B. Newby, as consulting petroleum geologist in Tulsa. This connection continued for only a year, and was terminated when all members of the firm entered military service. Garrett enlisted in the Aerial Photographic Section of the Army, and was assigned to a Cadet Officers Training School at Ithaca, New York. His work here was of such character that his notes and outline of the course were used in preparation of a textbook. He had qualified for a Commission when the war terminated, being one of three from a class of 300 who were commissioned as 2nd Lieutenant.

Following discharge from the Army he became associated for a short time with the Sinclair Oil Corporation, working in the Tampico region of Mexico. Meanwhile, M. J. Munn had resigned from the Gypsy Oil Company and organized the Riverland Oil Company, staffed chiefly with former associates of the Gypsy. On his return from Mexico Bob joined the Riverland and remained with this group until 1922. To him is due much of the early success of that company.

In July, 1922, Robert E. Garrett established himself in Tulsa as an independent geologist and oil producer, continuing this work until his death. Devoting most of his attention to Oklahoma, his energy, ability, and enthusiasm brought him more than average success. His geologist colleagues knew that if Bob produced a map it would "stand up," and he enjoyed the confidence of business associates in no less degree. Professional and business integrity were outstanding characteristics.

On June 15, 1920k Robert Garrett was united in marriage to Zola Zook, of Gibson

City, Illinois, who survives him. Their was a singularly happy married life, their chief interests being in their home, their friends, and their mutual hobby of collecting glassware and porcelain. Their collection is famous, and fills every room of the home, but Bob was ever ready to make a trip to some out of the way place where new treasures might be found. Despite this hobby there still was time for field work and for hunting.

Bob joined the A.A.P.G. in 1921. He was an early member of the Tulsa Geological Society, and its president in 1943–1944. He was a member of Boston Avenue Methodist Church of Tulsa, of the Tulsa Chamber of Commerce, a 32nd degree Mason, and a Knight Templar. Readily supporting any worthy civic cause, he perhaps more commonly supported his own private philanthropies of which his closest friends knew little. Modesty was an outstanding characteristic.

Surviving also are his mother and four sisters, for whom he had a deep regard and affection. To them and to the wife go the deepest sympathy from all Bob's friends, which is from all who knew him.

J. V. HOWELL

Tulsa, Oklahoma
September 5, 1947

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 11 (NOVEMBER, 1947), PP. 2085-2088

# AT HOME AND ABROAD

## CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

The Eighth General Assembly of the International Union of Geodesy and Geophysics is to be held at Oslo, Norway, August 17–28, 1948. Information may be obtained from J. W. Joyce, 6641 32d Street, N. W., Washington 15, D. C.

RALPH EVANS has resigned his position as district geologist with the Standard Oil Company of Texas, in San Antonio and is now exploration geologist with the P. R. Rutherford Oil Corporation, Houston, Texas.

HUGH D. MISER, of the United States Geological Survey, Washington, D. C., has been working in Oklahoma this fall, gathering data for a new edition of the geological map of Oklahoma. He made his temporary headquarters at the Oklahoma Geological Survey, ROBERT H. DOTT, director, at Norman.

M. MELVILLE JOHNSON is with the Husky Refining Company, Cody, Wyoming.

FRANK REEVES, of Kensington, Maryland, is continuing his work in Victoria, Australia, for the Vacuum Oil Company, Pty., Ltd. at Melbourne.

W. F. BOWSER has resigned his position as chief geologist of the Sunray Oil Corporation to join the R. W. Rine Drilling Company in Wichita, Kansas.

The A.A.P.G. committee on Boy Scouts literature had several meetings during the sessions of the Big Horn Basin field trip at Cody, Wyoming, August 4–8. Members in attendance were: DON L. CARROLL, MARTIN VAN COUVERING, who represents the Pacific Section on the committee, E. C. DAPPLES, R. C. SPIVEY who represents the West Texas Geological Society, W. T. THOM, JR., and FRANK GOUIN, chairman. In addition, several persons attended the meetings as advisors, including C. MAX BAUER and A. I. LEVORSEN. As a result of the meetings the chairman is to prepare outlines for suggested Merit Badge pamphlets for the Boy Scout program on physiographic and geologic subjects. These outlines are to be assigned members of the committee to complete. The committee also worked out a plan to have a graduate student spend the summer of 1948 at the Philmont Senior Scout Ranch at Cimarron, New Mexico. This plan is possible through the hearty cooperation of the Boy Scout authorities at Philmont and the West Texas Geological Society. So far, the experience of this committee with Boy Scout authorities is that of whole-hearted cooperation.

The 100th anniversary of the American Association for the Advancement of Science will be celebrated in Washington, D. C., from September 13 to 17, 1948. The A.A.A.S. annual meeting tentatively planned for the Christmas week of 1948 in New York City will be held instead in New York, December 26 to 31, 1949.

B. B. WEATHERBY, president of the Geophysical Research Corporation, Tulsa, Oklahoma, is chairman of the scientific and technical committee for the silver anniversary of the International Petroleum Exposition and Congress to be held at Tulsa, May 15–22, 1948. K. K. Kimball, consulting geologist, is secretary.

W. J. HILSEWECK, of the Gulf Oil Corporation, Midland, Texas, has resigned to become chief geologist of the Republic Natural Gas Company, Dallas, Texas.

WALTER E. LONG, formerly with the Magnolia Petroleum Company, is in charge of the new geological office of Geir-Jackson, Inc., Tyler, Texas.

JOHN R. FANSHAWE has left the General Petroleum Corporation at Casper, Wyoming, to become Rocky Mountain division geologist with the Seaboard Oil Company of Delaware.

E. E. ROSAIRE spoke on "The Economic Philosophy of the Professional Engineer and Scientist," at the meeting of the Houston Geological Society, October 13.

MERRILL A. STAINBROOK, who has been absent on leave during the past year, has returned to Texas Technological College, Lubbock, Texas, resuming his paleontological duties as a full professor in the department of geology.

KENNETH L. EDWARDS has left the Standard Oil Company of California. He is in the employ of the Richmond Exploration Company at Maracaibo, Venezuela.

ROBERT L. ANDERSON, formerly with the Chanslor-Canfield Midway Oil Company at Los Angeles, is now with Geophoto Services at Denver, Colorado.

M. G. CAPEN, former geologist for Superior Oil Company, is now with the Seaboard Oil Company of Delaware, Bakersfield, California.

CARL D. SMITH, consulting geologist and oil operator, died on October 10, at Stephens, Arkansas, at the age of 69 years. He graduated from the University of Arkansas, at Fayetteville, and studied at Stanford University, California, in 1905. He worked on the State surveys of Missouri and Arkansas, and the United States Geological Survey. He was the author of several bulletins of the U.S.G.S. At one time he was active as a consultant and operator in the development of oil fields in Oklahoma.

HENRY CASELLI RICHARDS, professor of geology and mineralogy at the University of Queensland, Brisbane, Australia, died at the age of 62 years, on June 6.

GLEN M. RUBY and C. L. MOHR have been engaged in geological reconnaissance in Portugal for the Axel Johnson Company of Sweden.

JOHN T. LONSDALE, director of the Texas Bureau of Economic Geology, Austin, spoke on "Geology of the Big Bend Region of Texas," before the South Texas Section of the A.A.P.G., at San Antonio, October 20.

J. D. PATE, of the Republic Natural Gas Company, Oklahoma City, discussed "Geology and Oil Resources of Cotton County, Oklahoma," at the meeting of the Tulsa Geological Society, October 20.

The National Geophysical Company, Inc., announces the removal of its executive and accounting offices from the Tower Petroleum Building to 8800 Lemmon Avenue, Dallas, Texas. The new location will house the company's main offices, laboratory, research department, and drill shop.

WALLACE E. PRATT, past-president and Powers Memorial medallist of the A.A.P.G., has been named by the American Institute of Mining and Metallurgical Engineers to receive the Anthony F. Lucas Petroleum Gold Medal for "distinguished achievement in improving the technique and practice of finding and producing petroleum." The award will be presented at the annual meeting of the A.I.M.E. in New York, February, 1948.

H. H. RENZ has been transferred from the Shell Company in Lima, Peru, to the Caribbean Petroleum Company, Maracaibo, Venezuela.

DON G. VIEAUX has left the United States Geological Survey to work for the Phillips Petroleum Company, Denver, Colorado.

HAROLD M. HORTON is with the Superior Oil Company of Venezuela, Caracas.

FRANK A. MORGAN, JR., recently with the British American Oil Producing Company, is in the employ of the Stanolind Oil and Gas Company, Salt Lake City, Utah.

HARRIS J. COX is with the Western Geophysical Company, Int., Casilla 654, Asunción, Paraguay.

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DISTINGUISHED LECTURE TOURS

E. DEGOLYER, of DeGolyer and MacNaughton, Dallas, Texas, honorary member and former president of the Association, was an A.A.P.G. distinguished lecturer, with the subject, "Prospecting for Petroleum," appearing before the following groups in October and November.

| | | |
|---|---|---|
| *October* | | |
| 1 | Ardmore Geological Society | Ardmore, Okla. |
| 2 | Oklahoma City Geological Society | Oklahoma City, Okla. |
| 3 | Tulsa Geological Society | Tulsa, Okla. |
| 6 | Yale University | New Haven, Conn. |
| 7 | Eastern Section, A.A.P.G. | New York, N. Y. |
| 8 | Pittsburgh Geological Society | Pittsburgh, Pa. |
| 9 | Ohio State University | Columbus, Ohio |
| 11 | Indiana-Kentucky Geological Society | Evansville, Ind. |
| 13 | Illinois Geological Society and University of Illinois | Champaign, Ill. |
| 14 | University of Wisconsin | Madison, Wis. |
| 15 | University of Iowa | Iowa City, Iowa |
| 17 | Kansas Geological Society | Wichita, Kan. |
| 20 | Dallas Geological Society | Dallas, Tex. |
| 21 | Corpus Christi Geological Society | Corpus Christi, Tex. |
| 22 | Houston Geological Society | Houston, Tex. |
| 23 | South Louisiana Geological Society | Lake Charles, La. |
| 24 | New Orleans Geological Society | New Orleans, La. |
| 25 | Southeastern Geological Society | Tallahassee, Fla. |
| 27 | Mississippi Geological Society | Jackson, Miss. |
| 28 | Shreveport Geological Society | Shreveport, La. |
| 29 | East Texas Geological Society | Tyler, Tex. |
| *November* | | |
| 3 | Fort Worth Geological Society | Fort Worth, Tex. |
| 4 | North Texas Geological Society | Wichita Falls, Tex. |
| 5 | Panhandle Geological Society | Amarillo, Tex. |
| 6 | Texas Technological College | Lubbock, Tex. |
| 7 | West Texas Geological Society | Midland, Tex. |
| 10 | Pacific Section, A.A.P.G. | Los Angeles, Calif. |
| 11 | San Joaquin Valley Geological Society | Bakersfield, Calif. |
| 13 | Rocky Mountain Association of Geologists | Denver, Colo. |
| 15 | Wyoming Geological Association | Casper, Wyo. |

RAYMOND C. MOORE, of the University of Kansas, Lawrence, is discussing "Problems of Sedimentary Facies," before the following groups in November and December. This lecture is the second of the current season in the Association distinguished lecture series.

| | | |
|---|---|---|
| *November* | | |
| 10 | Ohio State University | Columbus |
| 11 | Michigan Geological Society | Lansing |
| 13 | University of Illinois | Urbana |
| 14 | University of Iowa | Iowa City |
| 17 | Tulsa Geological Society | Tulsa, Okla. |

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|---|---|---|
| 18 | Shawnee Geological Society | Shawnee, Okla. |
| 20 | Ardmore Geological Society | Ardmore, Okla. |
| 21 | Dallas Geological Society | Dallas, Tex. |
| 24 | Houston Geological Society | Houston, Tex. |
| 25 | Corpus Christi Geological Society | Corpus Christi, Tex. |
| 26 | South Louisiana Geological Society | Lake Charles |
| 28 | Southeastern Geological Society | Tallahassee, Fla. |
| *December* | | |
| 1 | Mississippi Geological Society | Jackson |
| 2 | East Texas Geological Society | Tyler |
| 3 | Forth Worth Geological Society | Fort Worth, Tex. |
| 5 | West Texas Geological Society | Midland |
| 8 | Pacific Section, A.A.P.G. | Los Angeles, Calif. |
| 10 | Northern California Geological Society | San Francisco |
| 12 | Wyoming Geological Association | Casper |
| 15 | Rocky Mountain Association of Geologists | Denver, Colo. |

## ADDITIONAL APPLICATIONS APPROVED FOR PUBLICATION

(*Continued from page 2077*)

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Meetings will be announced. Visiting geologists and friends are welcome.

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Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. The Society sponsors the Kansas Well Log Bureau, 412 Union National Bank Building, and the Kansas Well Sample Bureau, 137 North Topeka.

## LOUISIANA

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Meets monthly, September to May, inclusive, in the State Exhibit Building, Fair Grounds. All meetings by announcement.

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Meetings: Monthly, November through May, at Michigan State College, East Lansing, Michigan. Informal dinners at 6:30 P.M., followed by discussions. Visiting geologists are welcome.

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Tower Building

Meetings: First and third Thursdays of each month, from October to May, inclusive, at 7:30 P.M., Edwards Hotel, Jackson, Mississippi. Visiting geologists welcome to all meetings.

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Shawnee

Meets the fourth Thursday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

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Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder. Luncheons: Every second and fourth Thursday of each month, at 12:00 noon, Y.W.C.A.

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Box 661, Gulf Oil Corporation

Meetings: First and third Mondays, each month, from October to May, inclusive, at 8:00 P.M., University of Tulsa, Kendall Hall Auditorium. Luncheons: Every Friday (October-May), Chamber of Commerce Building.

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Meetings: Luncheon 1st and 3d Wednesdays of each month, 12:00 noon, Herring Hotel. Special night meetings by announcement.

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Luncheons: Each week, Monday noon, Blackstone Hotel.

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Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

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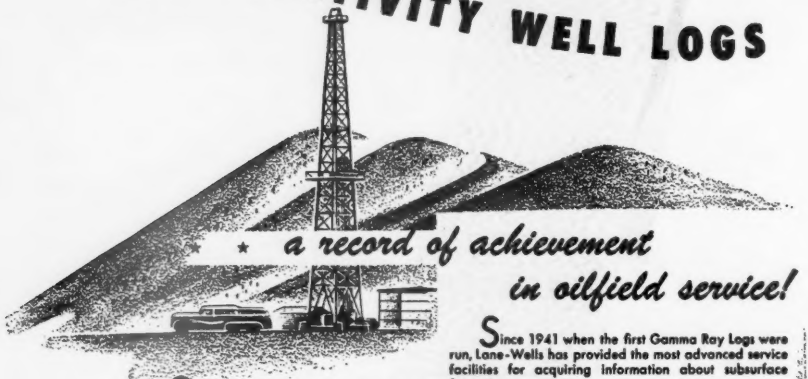

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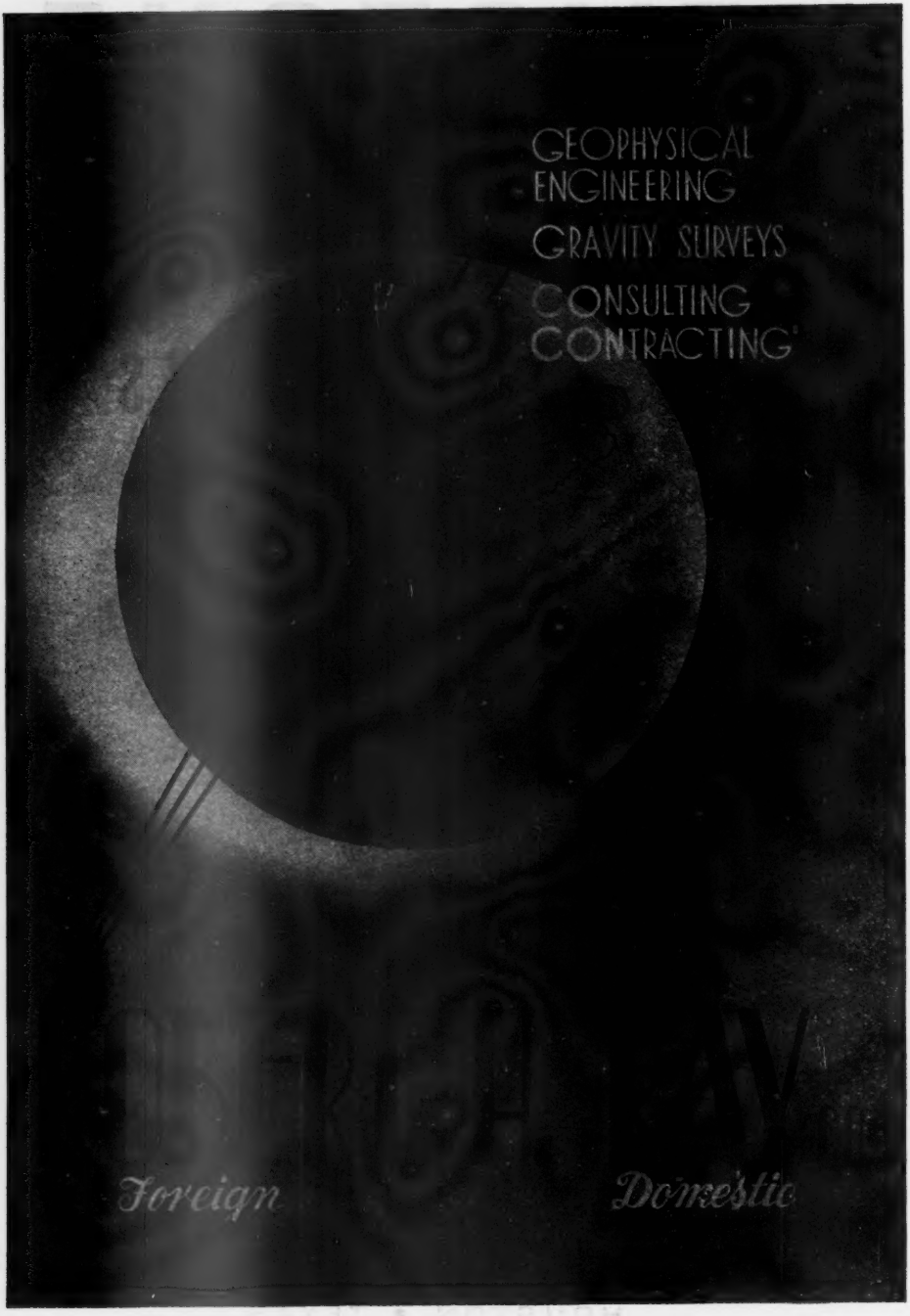
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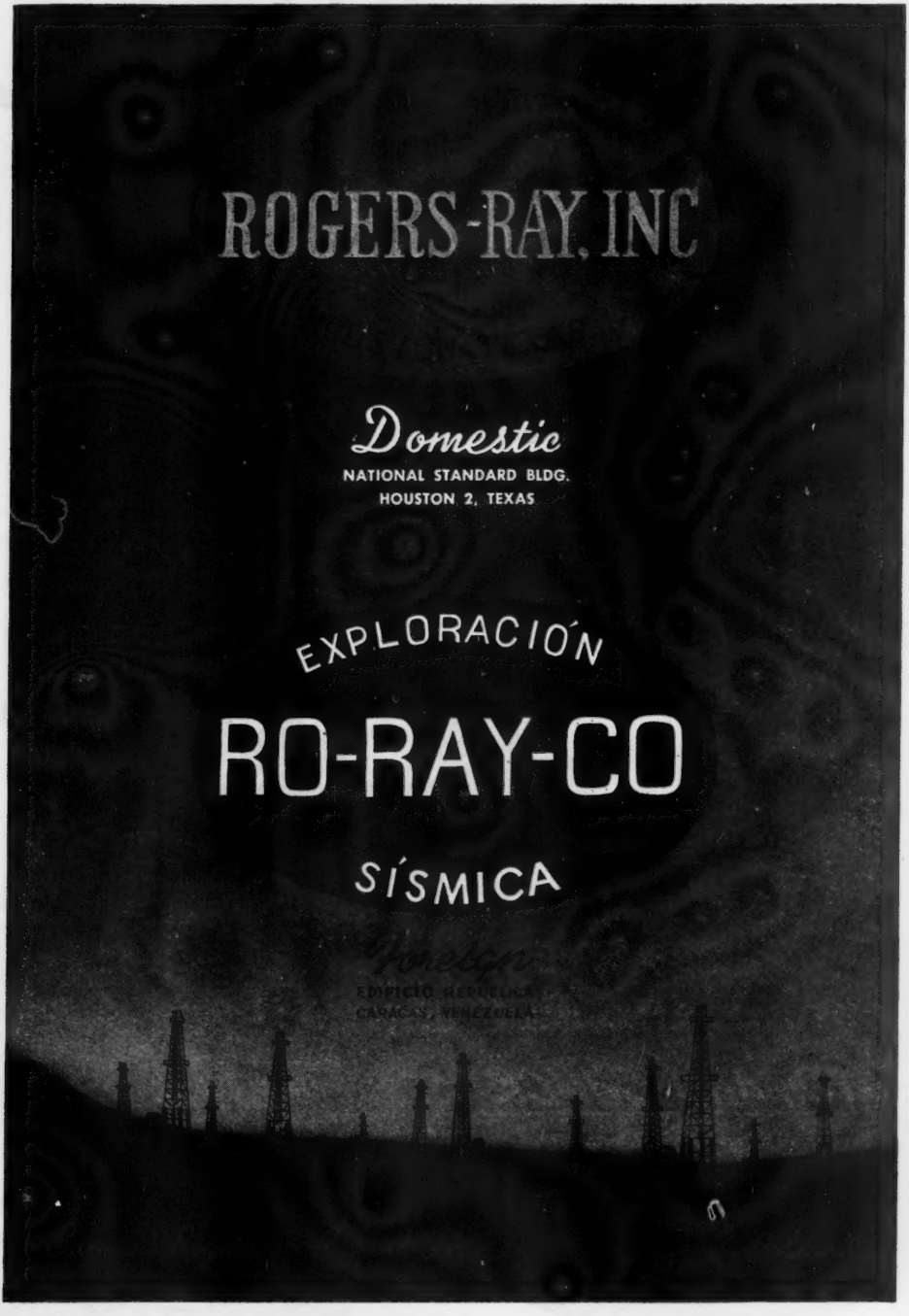
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# SULLIVAN

# "200"

## PORTABLE DRILL RIG

**FOR STRUCTURE TESTING**

**CORE DRILLING**

**ELECTRICAL LOGGING AND**

**SHALLOW SLIM-HOLE PRODUCTION DRILLING**

This medium weight, heavy duty rig, completely portable with 20,000 lb. drilling string capacity. Its hydraulic feeding mechanism features the automatic hydraulic chuck. Kelly drive and rotary table are optional. Equipped with two motors to prevent "down time."

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**ON SULLIVAN DRILLS**

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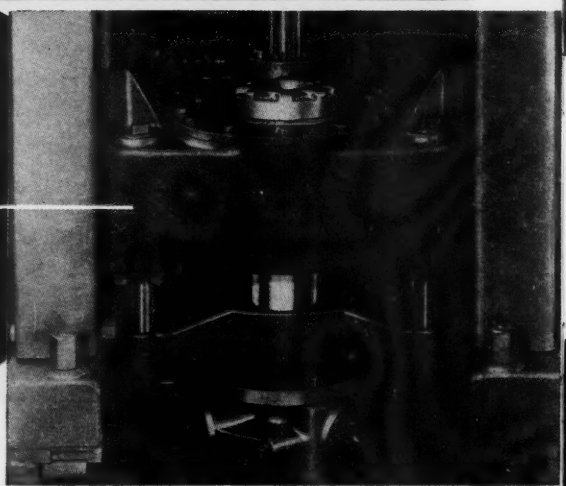
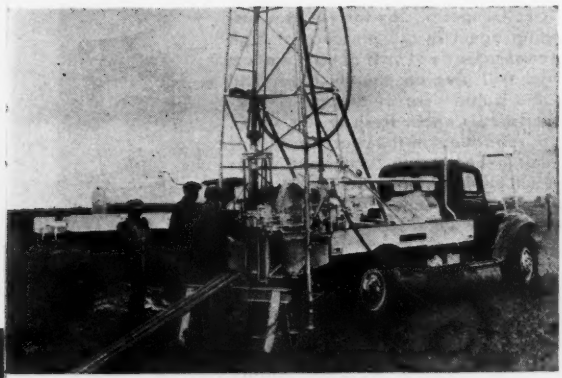
Developed by Sullivan, the automatic chuck is a hydraulic improvement that eliminates hand set screws, saves an average of 30 seconds per rod change . . . enough time to drill 200 more feet a day.

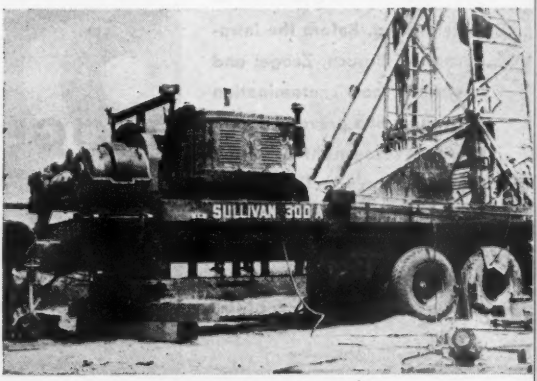


# HYDRAULICS

## *Save Time... Reduce Costs... Get more Footage per day... accurately!*

**Hydraulic features found only on Sullivan Motorized Drill Rigs have a proved record of speed, safety and economy in structure testing and exploratory drilling. Sullivan Hydraulics save time in rod and location changing, feeding and retracting, handling break-out tongs and make-up, raising and lowering the mast. And, time converted to accurate, profitable drilling assures a sharp reduction in costs.**






### MODEL 37
**DRILLS HOLES TO 1200 FEET**

A light, sturdy portable for shot hole, shallow structure testing or blast hole drilling. 1200 ft. capacity for 2" core or 850 ft. of 6" hole.

### MODEL 300A
**DRILLS HOLES TO 3500 FEET**

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# JOY MANUFACTURING CO.

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# Baroid offers a TRIPLE THREAT against salt water contamination

**These three products, developed by Baroid Sales Division, enable operators to drill through salt or salt-water formations and minimize the hazards usually encountered in their drilling. Before the introduction of Baroco, Zeogel and Impermex, salt contamination of drilling mud prevented complete development of many potentially productive areas. Used individually or in combination, these three products will help defeat the toughest salt-water drilling problem.**

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BAROCO—A high-yield, salt-water-resisting drilling clay. Baroco has been compounded for use in formations containing moderate quantities of salt (less than 10 or 12 per cent) or other oil field electrolytes which may flocculate ordinary drilling muds. Because of its high yield, approximately 40 barrels of 15-centipoise mud per ton of Baroco, it finds wide use in preparation of starting muds or workover muds where weights of 9.0 pounds per gallon (67 pounds per cubic foot) are sufficient.

## 2 ZEOGEL

ZEOGEL—A special clay for use as a suspending agent in the presence of high concentrations of salt or salt water. Zeogel will give an equally high yield and stable viscosity and gel characteristics in either fresh or salt water, or regardless of the concentration of salt in the latter. A Zeogel-and-water mud will prove a highly satisfactory drilling mud under conditions which do not require a low water loss.

## 3 IMPERMEX

IMPERMEX—A water-dispersable organic colloid. Impermex, which can be used with either Baroco or Zeogel, will decrease the water loss of drilling muds to a greater extent than can be obtained with the best clays and bentonites, even in muds highly contaminated with salt, salt water, cement, or with any other water-soluble contaminant.

To obtain additional information on how to apply Baroco, Zeogel and Impermex to the well or wells in your district, please fill out and mail the form below to Baroid Sales Division, P.O. Box 2558, Terminal Annex, Los Angeles 54, California.

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Company_____

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**NATIONAL LEAD COMPANY**
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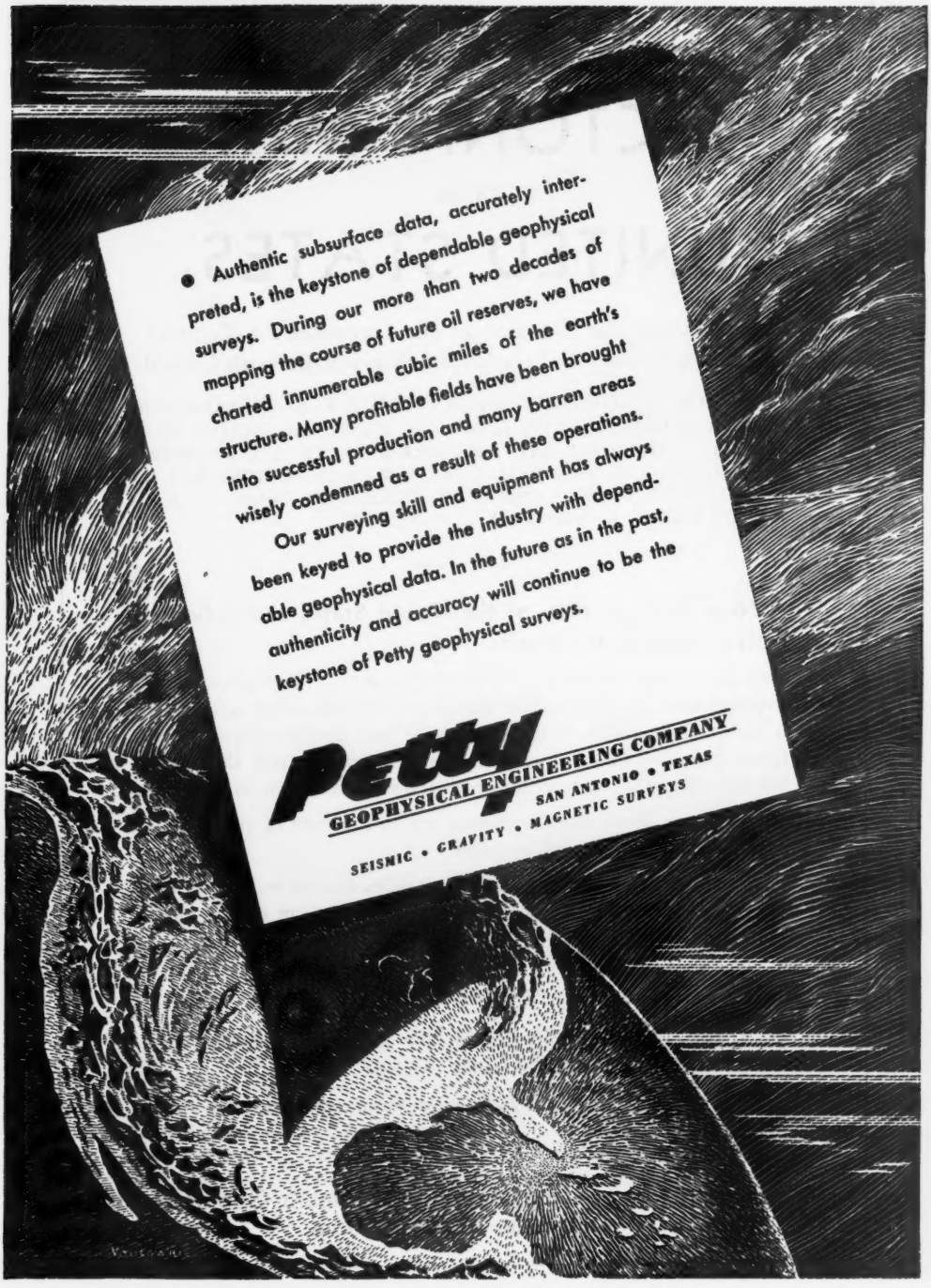
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Our surveying skill and equipment has always been keyed to provide the industry with dependable geophysical data. In the future as in the past, authenticity and accuracy will continue to be the keystone of Petty geophysical surveys.
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**An A.A.P.G. Publication!** **Second Printing, 1947**

# TECTONIC MAP

Of The

# UNITED STATES

Prepared under the Direction of the Committee on Tectonics, Division of Geology and Geography, National Research Council.

CHESTER R. LONGWELL, Chairman, PHILIP B. KING, Vice-Chairman
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**This equipment as well as the Portable Gravity Meter, other geophysical apparatus and precision equipment is manufactured in our own Laboratories.**

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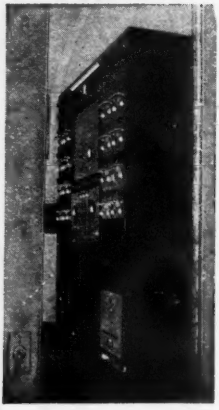

This complete 16 channel, dual recording unit is mounted in a special stainless steel body, having two power driven cable reels, completely wired, tested and ready for field service. Amplifiers have full, automatic amplitude control and complete rejection of 60 cycle power line interference. It has inverse feed back filters, 6 filter settings controlled by selector switch on instrument panel, which makes it possible to obtain any 6 filter curves. Interchangeable plug-in type filter units make it possible to readily change complete system of filter curves. Dual output is available, providing for mixed and unmixed recording simultaneously. Light weight seismometers are furnished with either fluid or electro-magnetic damping.

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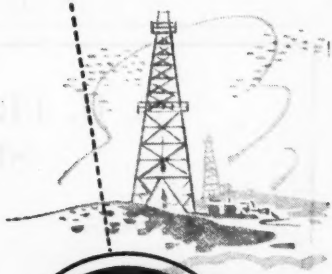

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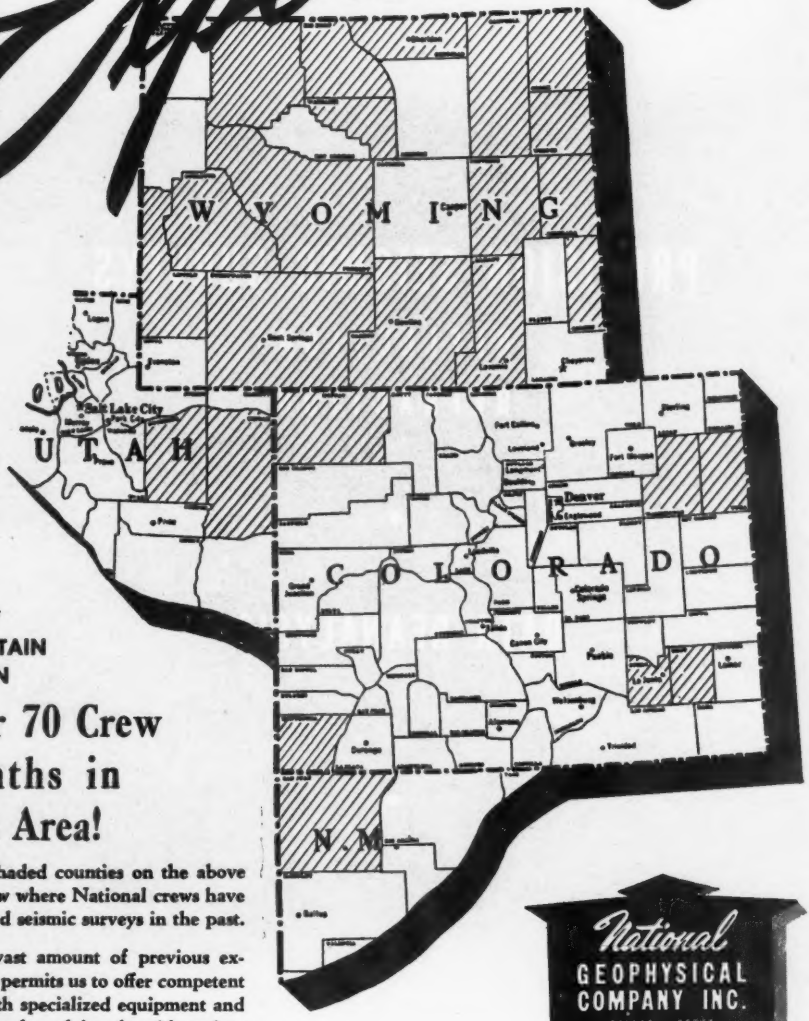


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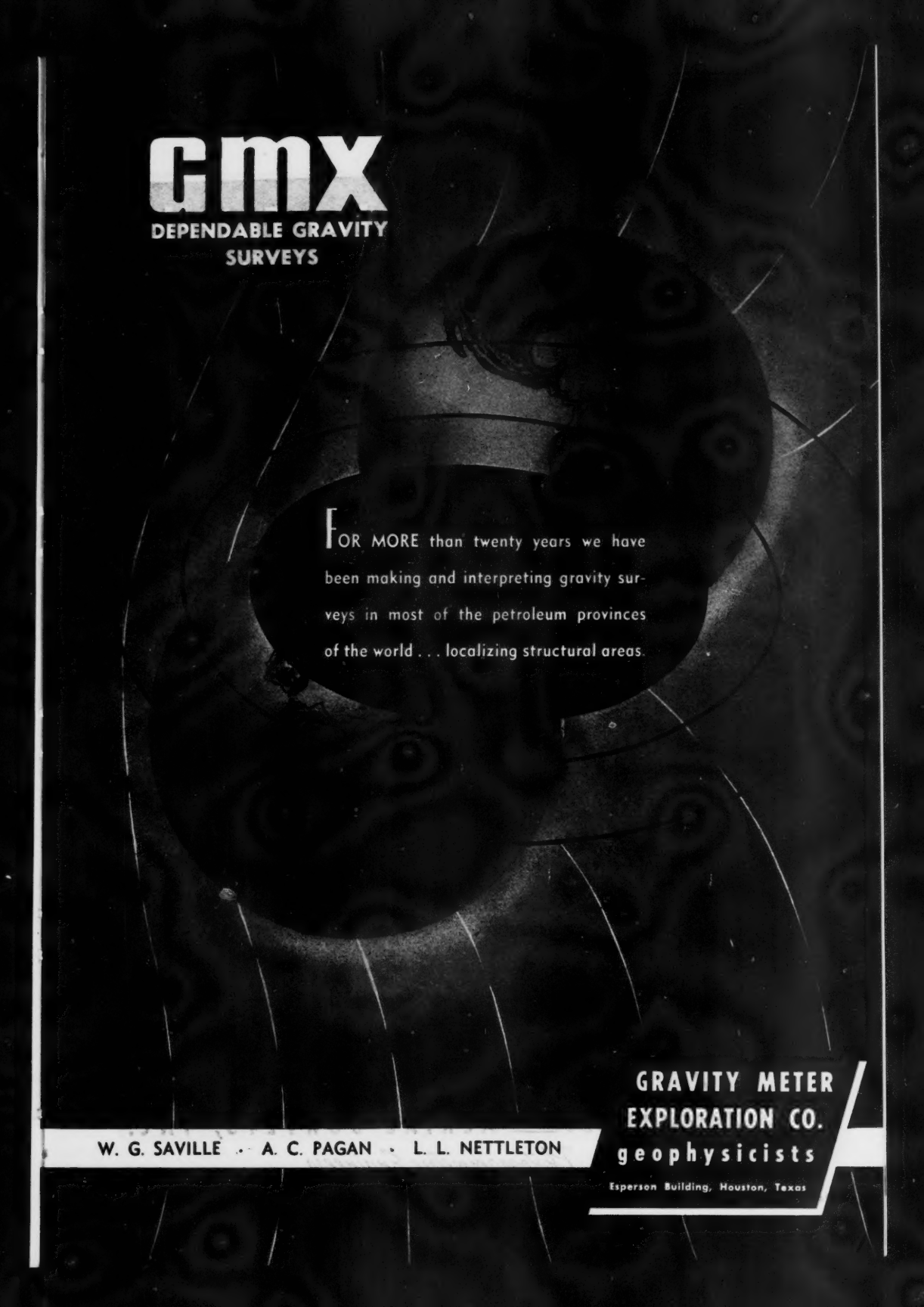

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**. . . and how it secures accurate cores WHICH . . .**

Eliminate danger of passing up productive sands

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Make it possible to select proper casing locations

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Offer positive proof of oil-bearing sands

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Permit study of character of formations

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Are readily analyzed for porosity, permeability, etc.

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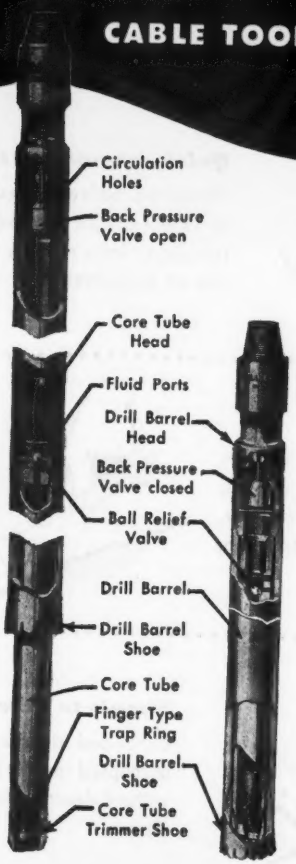


Takes good cores from wide range of formations

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Cores are accurate, uncontaminated samples

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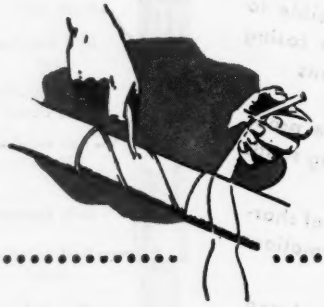

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Unneeded cartridges can be uncoupled rapidly by one man, without damage to charge or sleeve.

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# "QUOTE" from The New York Times

## Topics of The Times

**Letters With Enclosures** We have been receiving letters lately from presidents of big corporations and allied co-ordinating agencies. It is not an attention to which this modest corner is accustomed, and we are the more interested. Enclosed in the letters are reprints of advertisements which have appeared in newspapers and magazines, and which, aside from the obvious purpose of grinding a particular axe, seek to drive home one point. It is that the spirit of rivalry has made this country what it is.

### *Sauce for The Goose*

The controls to which we have all been subjected for the supposed benefit of the country and all of us, have, we know, been hopefully designed to curb the excesses into which the spirit of rivalry drives some of us. And undoubtedly these controls have been at times necessary and even salutary. But this reading and pictorial matter raises sharply the question whether the continuance of the process of curbing a spirit so vital may not kill the goose—pardon the domestic bird in this connection and remember that geese saved Rome—that laid the golden egg out of which our extraordinary prosperity was hatched. And it suggests that the spirit which inhabits the egg is precisely the thing we can least afford to lose and remain the arch-exemplars of enterprise we take ourselves to be.

### *Pictures Tell the Story*

Some of the advertisements, done in brilliant colors, undertake to expose to us the very mainspring of American enterprise. One shows two lad boys and a girl of corresponding age. One of the boys is inviting admiration by juggling with three balls in the air. The other is meeting the challenge by parading his ability to balance himself, and using the top of the back-yard fence as a tight rope. Another picture also introduces a back-yard fence. In this case the amateur gardener on our side of the fence is crouched among his tomato plants and proudly holding up a particularly fine specimen for the admiration and envy of his neighbor on the other side of the fence. That neighbor, with a broad grin, is meeting the challenge by displaying a rival specimen—a tomato seemingly just as big and rosy.

### *Multum in Parve*

The spirit of rivalry, the accompanying letter says, is what has enabled the petroleum industry to achieve the progress which has brought such benefits to everybody. And this spirit of rivalry is no different from that which inspires the lad boys and the amateur gardeners .....

### *Mark Twain Is Responsible*

No mention is made by the petroleum spokesman of the use to which Tom Sawyer put the spirit of rivalry when it came to a whitewashing job. That, we submit, is a classic example of American enterprise, and one which, in the past, has not lacked admiration—or imitation in circles less juvenile. In such cases it has been roundly denounced as exploitation.

In Tom Sawyer, too, the American spirit spoke—and spoke in native accents. But the accent today is no longer on exploitation. Rivalry has become not a race for private profit but the firm foundation upon which rests the entire fabric of our national economy. It must be preserved.

*Reprinted courtesy of The New York Times*

***Write to:* Public Relations Operating Committee, Dept. 1F, American Petroleum Institute, 670 Fifth Avenue, New York 19, N. Y., for NEW FREE Plan Book that helps *YOU* benefit *locally* from this campaign.**

S. E. C.
Service Interpretation

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GRAVITY METER SURVEYS
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Very truly yours,

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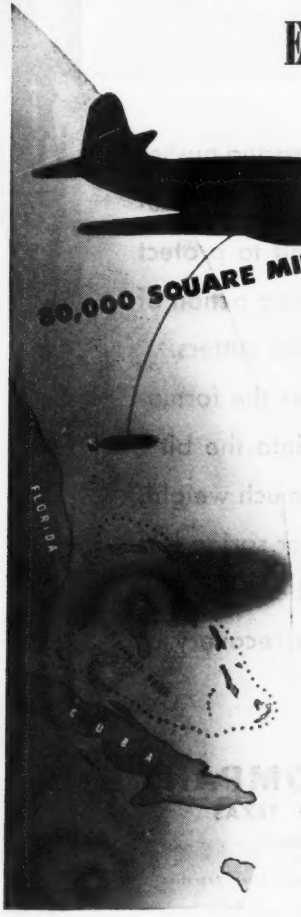


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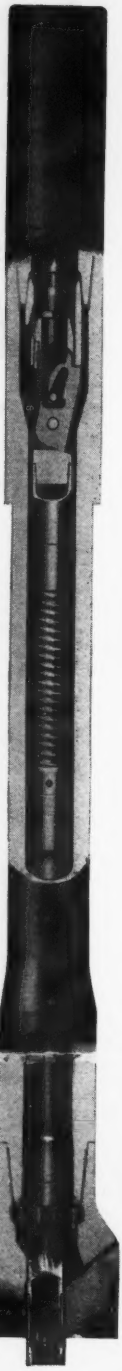

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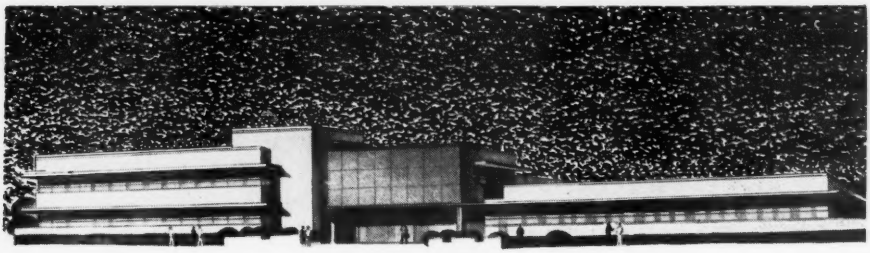

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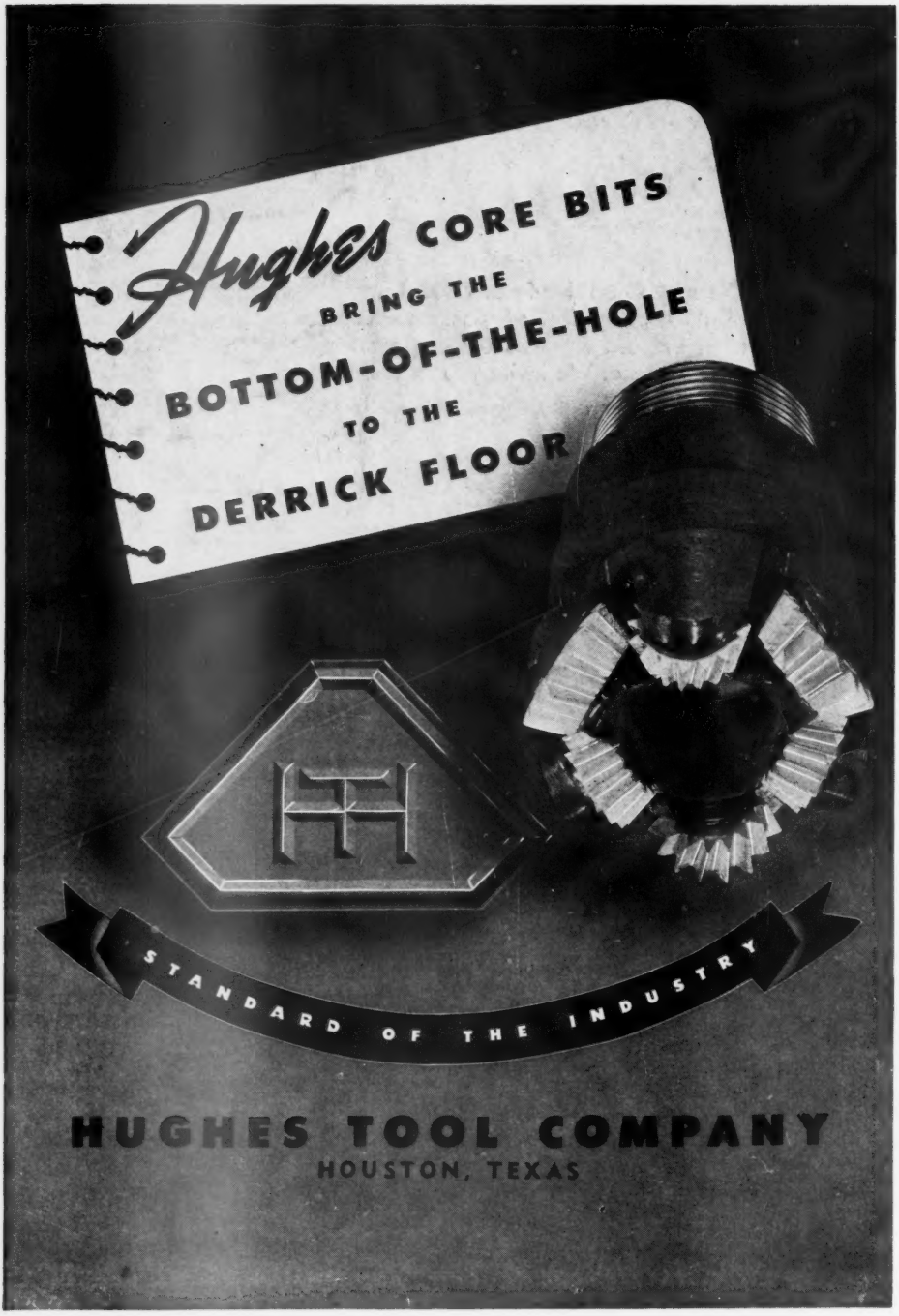
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